Automated generation of web server fingerprints

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ABSTRACT
In this paper, we demonstrate that it is possible to automatically generate fingerprints for various web server types using multifactor Bayesian inference on randomly selected servers on the Internet, without building an a priori catalog of server features or behaviors. This makes it possible to conclusively study web server distribution without relying on reported (and variable) version strings. We gather data by sending a collection of specialized requests to 110,000 live web servers. Using only the server response codes, we then train an algorithm to successfully predict server types independently of the server version string. In the process, we note several distinguishing features of current web infrastructure.

1. INTRODUCTION
One of the fundamental tactics used by both attackers and defenders is to understand what specific systems might be under attack or require defense. Individual point releases will have known software bugs for which off-the-shelf exploits may already be available. [7] While web servers often need to know a browser’s specific user agent, e.g., to deliver content that works around known software bugs for which off-the-shelf exploits may already be available, [7] while web servers often need to know a browser’s specific user agent, e.g., to deliver content that works around known bugs or missing features of a given web client, web clients have no particular reason to know the exact version of a web server. This leads to a common mitigation, where a web server administrator will deliberately obfuscate version strings. When a server gives commodore64-HTTPD/1.1 or ’DROP TABLE server-types; – as its version string, this behavior is obvious, but it is difficult to measure the frequency at which such modifications occur, or the true types of servers with obfuscated names.

Historically, extensive work has been done on fingerprinting operating system kernels [3], and traffic classification [11], often making use of probabilistic techniques [5], and on fingerprinting web browser configurations [21], among other areas. While various commercial applications use known distinguishing features of different web servers to identify server types and versions [16], surprisingly little academic work has been conducted on the topic of web server fingerprinting, and much of what has been done has focused on detecting or preventing fingerprinting [20].

In our research, rather than manually cataloging every possible quirk, we wish to take a machine learning approach, sending a variety of carefully crafted requests to large numbers of web servers on the Internet, and training our system to make subsequent identifications. We take advantage of the fact that many installations don’t obfuscate their published version information, allowing us to train our models with remarkable accuracy.

2. DESIGN AND METHODOLOGY
Our central design principle was to determine if variations in web server behavior made it possible to determine server type (e.g. Apache) and version (e.g. 2.2.3) without a manual analysis of individual pieces of software. We undertook to do this by surveying a broad selection of running web servers and comparing their responses to various requests. In the process, we gathered information on some behaviors and features that might be related to potential exploits either against either the servers themselves or against browsers accessing the servers.

The HTTP Protocol. Knowledge of the HTTP protocol is necessary to understand web server behavior and variations. First documented with version 0.9 in 1991, the HTTP protocol is now standardized on version 1.1, released by the Internet Engineering Task Force in its RFC 2068 of January 1997 [5], and updated with RFC 2616 in June of 1999 [6]. While the basic format of the protocol is relatively straightforward, there is significant opportunity for different implementations of the protocol to behave differently, particularly in selecting among the 41 different response codes included in the protocol. Furthermore, many request and response headers are optional, and their ordering is not specified by the protocol. This means that different server implementations will have measurably different behavior that can be used for the purpose of classification, even when the question of incomplete and incorrect implementations is set aside. These variations, described in part below, make it possible to identify server types and versions by the various ways the protocol is implemented.

In designing our experimental methodology, it was essential not to compromise or damage any of the servers that we studied. Therefore we chose a selection of correct, if somewhat unusual, HTTP requests, and analyzed the responses. We chose requests that would enable us to gather identifying information about the servers — not simply the basic HTTP version string that nominally represents the server type and version, but also a set of responses that should enable the identification of the server based on its behavior, and not only on its reported type. In designing our experimental methodology, we also sought to obtain aggregate data about large numbers
of servers, as opposed to a detailed understanding of the security profile of a few selected sites, and so we chose an approach that involved crawling a large number of sites and cataloging responses, rather than a manual inspection of a few hosts.

2.1 Bayesian Classification
Bayes’ rule is a basic principle of probability that allows one to calculate the probability of a given hypothesis given a certain datum, when one knows the correlation between the datum and the hypothesized conclusion in the universe being considered. Consider the common application of spam filtering, where Bayesian classification has been found to be extremely effective, even in the face of dedicated attempts to defeat it [1]. If one considers the presence of a certain term in an e-mail as the datum in question, as well as the frequency of that term in both spam and non-spam e-mails, then Bayes’ rule makes it possible to classify the probability that a given e-mail is spam based on the presence of that term. Bayesian inference allows multiple observations of this type to be combined, potentially allowing for more accurate classification of the e-mail as spam or not. Bayesian techniques have been used effectively for intrusion detection [12], data mining [4], and as an effective technique in fields well beyond the scope of computer science [8].

Our application is somewhat more complex than spam filtering, as we need to classify servers as belonging to one of many categories of types, and not simply as a binary quantity (spam or not spam.) In doing so, we use Bayes’ rule to calculate the probability of a given server belonging to each server type, and choose the type with the highest probability. (See Section 2.4) This also enables us to associate a degree of certainty with our predictions, as we know the likelihood that our observed characteristics belong to our calculated server type [9].

2.2 Selection of Requests
In developing our experimental methodology, we selected 10 separate requests to send to every surveyed server. A summary of the requests and their purposes is shown in Table 1. While we begin with a standard HTTP GET to provide a baseline, the other requests are intended to identify features that may have different (or missing) implementations across different web servers. They were also chosen with the aim of receiving the same response regardless of site configuration. Thus, the only files that we access directly are files that should be present on most servers: the root URL, the robots.txt file, and the favicon.ico file. While these files may not be present on every server, their presence on most servers enables a broad comparison across sites independent of site content.

2.3 Datasets
We prepared three distinct data sets. The first consisted of responses from the Alexa top 10,000 sites, the second consisted of responses from the top 100,000, and the third consisted of responses from the last 10,000 sites in the Alexa top 1 million. These three data sets, representing a total of 1.2 million HTTP requests and responses, allowed us to abstract behavior for different server types, and to compare the differences between the largest (and presumably most carefully maintained) sites and other sites that are likely not as actively maintained or uniquely configured.

2.4 Prediction of Server Types
Our work sought to provide a methodology to identify server types beyond their self reported version strings. With this in mind, we

| Request | Rationale |
|---------|-----------|
| An ordinary get request against the root URL | This request provided a “baseline.” As the most ordinary request that any server would receive, we expected it to be handled in a straightforward manner with a 200 response code. |
| A partial get request of 50 bytes against the root URL | This request allowed us to test the server’s implementation of the HTTP partial get feature. |
| A conditional get request for pages modified after a future date against the root URL | This request allowed us to test the server’s implementation of the HTTP conditional get feature. |
| A head request against the root URL | This request allowed us to test the server’s implementation of the HTTP head feature. |
| An options request | This request allowed us to test the server’s implementation of the HTTP options feature. |
| A trace request against the root URL | This request allowed us to test the server’s implementation of the HTTP trace feature. |
| A request for the root URL as a CSS stylesheet | This request is similar to a request that might be generated by a browser experiencing a cross site scripting attack. A modern browser should watch the content type of the response, refusing to interpret the page as CSS if it is labeled as HTML. |
| A request for robots.txt as a CSS stylesheet | Similar to the previous request, it allows us to test mime type support on a different file type (text). |
| A request for a relative URL above the root directory | This request is invalid and should be rejected on any server. If it were honored, it would give the client access to the server’s entire file system. |
| A request for the favicon | This request allows us to survey another content type, again checking for proper MIME type support. |

Table 1: Requests used in measuring server behavior
collected the server response codes from the requests above, and used them to calculate a distinct fingerprint for each type of web server. We could then match the responses of an unknown web server against the fingerprints that we had developed for various server types, enabling us to predict its type and version.

We associated the individual fingerprints with specific server types and versions by using the version string provided with the responses. In doing so, we did not assume that the data in the version string was necessarily correct. Indeed, our premise was that it is often changed to report something other than the correct server type and version. However, we did assume that, as these changes are made by individual administrators acting independently, that there would not be a consistent incorrect server string for a given fingerprint. In this way, the incorrect responses, even if they constituted a significant percentage of the sample, could be filtered out as noise, while the single largest reported version string for any given fingerprint would be, in fact, the correct one.

Our fingerprints took the form of a dataset listing the frequency of each response for each server type and request type. We generated the fingerprint dataset by training on the raw data in our primary dataset, calculating the probability of a given server version given that server’s response to our requests using a standard Bayesian methodology, as discussed in Section 2.1.

\[ P(response|server) = \frac{P(response,server)}{P(server)} \]

Then, for each server in the set being tested, we sought to predict the probability of each server type. Assuming that the response to one request was independent from the response to a different request, we used Bayes’ rule to combine the probabilities for each request for each server type as follows:

\[ P(server | \bigcap_{i=0}^{n} response_i) = \frac{P(server) \prod P(response_i|server) \prod P(response_i|server)}{P(response)} \]

This gave us a probability for each server type given the total set of responses given site returned. We then selected the most probable server type as our prediction, reporting both the server type and the probability that we had generated.

2.5 Limitations

Some attempts at disguising a server’s type and version may go beyond changing the version string. For example, a program called ServerMask by Port 80 changes the format of headers, cookies, and file extensions to make Microsoft IIS resemble a different type of server. Because our techniques do not use those particular markers to fingerprint the server, those changes should not affect our success. However, software that manipulated the response codes could easily confuse our algorithm. Indeed, it is possible that some of the unusual response codes that we detected came from software seeking to do exactly that. Additionally, our methodology assumes that a single web address corresponds to a single server technology (which may or may not be distributed across multiple physical machines). However, in cases where different requests are handled by different server technologies (as may happen, for example, when separate caching servers are used) our attempts at identifying a single server technology used on the site can, at best, identify only one of the technologies used.

3. RESULTS

Having developed our techniques, we applied them to our data set, enabling us to validate our methods and discover several interesting behaviors of current web servers.

3.1 Distribution of Server Types

In order to determine the effectiveness of our technique, it was necessary to test it on real-world data. In doing so, we gathered information on server type from raw version strings, processed it with our algorithms, and examined the results.

3.1.1 Reported server types

While the HTTP standard provides for the use of “Product Tokens” (section 3.8) in the “Server” field of the response header (section 14.38) [6], many individual sites choose to modify their headers to exclude this information or replace it with irrelevant or incorrect data. Thus, we found server versions such as Nintendo, All your base are belong to us, and My Arse in addition to more standard strings such as Apache/2.2.20 (Ubuntu). This penchant for customization not only reflects the universal human desire for self-expression, but an understandable desire to hide sensitive information from potential attackers and competitors. The reported server types which we observed are summarized in Table 2.

3.1.2 Calculated server types

In order to correct for this behavior, we developed an algorithm (described above) that used multifactor bayesian analysis to predict the actual server type based on responses. Our algorithm produced different results from the server type returned by the site for approximately 38% of sites. Figure 1 shows the confidence levels of our predictions when our algorithm was trained on the top 100,000 sites, and run on the top 10,000 sites.

While for a number of servers, we were able to predict the server version with a very high confidence level, in other cases, it is not immediately clear whether the server was reporting incorrect data, or whether our algorithm incorrectly predicted the type of the server. As it was infeasible to contact the administrators of all servers in the sample to inquire as to the true server version, we relied upon the confidence levels produced by the Bayesian analysis. Even beyond this, however, some circumstantial evidence does suggest that...
our algorithm correctly predicted the results in many cases.

Apart from the fact that our analysis produced the same results as the server version string in 62% of cases, some of the divergent results also suggest correct behavior. For example, server versions which are derived from Apache, such as IBM HTTP Server and Apache Coyote, were recognized as Apache, even though they did not figure into the training data for Apache. Most sites with unusual and obviously false version strings were recognized as belonging to one of the major server types.

A more interesting question concerns the cases where servers with apparently correct version strings were recognized as servers of a different type. Are these cases of web site administrators seeking to intentionally obfuscate their server selection, or cases of erroneous behavior on the part of our software? As seen above, we were able to generate a confidence estimate for each of our predictions, and many of these results fell in the 75% confidence range, suggesting a likelihood that we were frequently correct, and the reported version strings represented an intentional effort at obfuscation.

3.1.3 Sites reporting multiple server types

One phenomenon that affected our analysis was the case of a number of sites that reported different server versions to different requests. Within the top 100,000 websites, we found that 6 servers gave 10 different version strings to our 10 requests, 84 gave 5 or more, and an astounding 24,254 sites gave at least two different version strings to our 10 requests. Within the top 100,000 websites, we found that 6 servers gave 10 different version strings to our 10 requests, 84 gave 5 or more, and an astounding 24,254 sites gave at least two different version strings to our 10 requests.

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While we have no direct evidence explaining this phenomenon, our data does suggest several possible conclusions. For example, a number of servers reported no server version at all, until they were asked for their favicon.ico, at which time they reported that they were running Microsoft-IIS. This suggested to us that a bug or configuration error in Microsoft-IIS revealed the server version on that particular request when an operator had desired it to be hidden.

On other sites, it would appear that our requests were, indeed, being handled by a variety of servers of different types. It would seem that some common requests may have gone to a server handling static content, while the more unusual requests got forwarded to a different server which, in turn, returned a different server string. It is conceivable that some web servers were configured to return different version strings to different requests, perhaps in an effort to confuse observers. However, we have no conclusive evidence to support this hypothesis.

3.1.4 Server Types

After running our analysis, we were able to classify the most common web servers found in our data set. The results are shown in Table 3.1. We give both the reported server types and the calculated server types for comparison. As can be seen, the 15% of servers which did not report a version have all been classified into one of the major versions.

Many servers are re-classified as Apache, bringing the relatively low number of Apache servers found in the top 10,000 sites up to

a level more typical of the internet as a whole. Because we assign all servers to the most likely category, even when our confidence in our estimates are low, this may result in various obscure server versions being classified as Apache with a low confidence rating. As the most common server type, Apache becomes the “best guess” when no good classification is possible.

Additionally, the number of servers reporting Microsoft-IIS can be seen to have increased. This is consistent with the known existence of software designed to obscure Microsoft-IIS servers. More interesting is the virtual disappearance of Microsoft-HTTPAPI servers. The Microsoft HTTP API is designed to let programs written in C service HTTP requests for specific URLs. It is a relatively low-level API, exposing basic HTTP functionality to the programmer. While there is no definitive way of knowing whether our re-classification of Microsoft HTTP API version strings was correct or not, it is worth noting that Microsoft HTTP API is not so much a server type as it is an interface for various programs to function as a web server. Thus, it seems likely that there is limited commonality between the way different programs making use of this API handled our requests. It may be the case that, because each program using this API is effectively a unique server type, that our algorithm was unable to effectively classify them.

Of the three smaller server versions, AkamiaGHost, cloudflare-nginx, and LiteSpeed, two are not server types at all, but content delivery networks. CloudFlare and Akamai specialize in hosting static content in locations close to users, enabling faster page retrieval. For this reason, it is not surprising that their servers should be re-classified as one of the common types — their server version strings represent a delivery network and not a version type. LiteSpeed, on the other hand, is a proprietary server technology. While it advertises itself as being “completely Apache interchangeable,” LiteSpeed does not advertise itself as being an Apache derivative. The general classification of LiteSpeed servers as Apache may reflect similarities in the behavior of the two servers as well as LiteSpeed’s small market share.

3.1.5 Apache Versions

In addition to the server type, the software version is an interesting topic of study. It provides information as to how up-to-date a server is, an interesting question both for study and for potential attackers. For this reason, we set out to see what information we could extract from our dataset regarding server versions.

Most servers in our dataset did not disclose their exact version, but a sufficient number provided the information to make some analysis possible. Because Apache servers possessed the largest market share — and hence, the most complete data — we chose to study their version strings in order to get a better understanding of the server population in active use. Although we have not studied other server types in the same detail, we expect these results to be similar to Apache derivatives and that the results can be generalized to other servers.

Our first step in studying the distribution of Apache servers was simply to examine the version strings returned by the servers themselves. As is shown in Appendix B, the version numbers of Apache servers in active use vary widely. While many are recent versions such as 2.2.22 and 2.2.23 (both 2012 releases) some servers use Apache versions dating from the late 1990s and early 2000s. Indeed, more than 10,000 responses of the 963,000 received from the top 100,000 sites reported some version of Apache 1.3, which
reached its end of life in 2010, although patches are still produced.

Server version strings, like server types, are subject to the caprice of site maintainers, who have an incentive to report incorrect information in an attempt at security by obscurity. Not only did slightly more than half of the servers reporting themselves as running Apache give no version details at all, but in the remainder, a few obviously false version strings such as “4.0.4” and “6.6.6” were returned. However, it is unclear how many of the plausible version strings are in fact false.

Using the same probabilistic techniques that we used to predict server types, we attempted to predict server versions. First, we took all of the servers that reported their server type as Apache, and trained our algorithm based on their reported versions from the top 100k. We then applied the trained algorithm to the smaller data sets, seeking to predict the version for servers reporting Apache. Unfortunately, the responses received from our queries did not meaningfully differentiate Apache versions. It is possible that variations among Apache versions might enable a researcher to determine Apache versions sending different requests or by measuring different properties in HTTP responses, but we leave this to future work.

### 3.1.6 Comparison with others’ results

One way to estimate the accuracy of our results is to compare them against other sources. Netcraft gives results for “all domains” — more than 625 million domains. They report the top servers as Apache with 57.2%, Microsoft with 16.5%, nginx with 11.9%, and Google with 3.4% [17]. These results are largely consonant with our findings, although the scale of the Netcraft survey is obviously much broader, and so the results can not be directly compared. In a similar survey of 63.5 million servers, Security Space reports Apache with 68.7%, Microsoft with 14.89%, and Other (presumably including nginx) with 16.17% of the market [18]. While the results are largely consistent, we did not have access to the methodology for these two surveys, so we were unable to determine if they were naively relying on server version strings, or using some more sophisticated method of identifying server software.

### 3.2 Server Responses

In analyzing our data, we found that web servers returned 44 different response codes, many of which do not form part of the official HTTP specification. The table in Appendix A illustrates the range of responses for our various requests. Some of these responses are particularly noteworthy. For example, when we request text and HTML documents as CSS, only a relatively small percentage of servers return code 406, indicating that the document can not be returned given the parameters sent by the client. Interestingly enough, the number of servers returning the response varied depending on the request. When we asked for a text file as CSS, 9,338 servers gave us a 406 error, while only 3,229 gave us that error when we asked for an HTML document as CSS. Much more common is code 200, sending the document despite the unusual request. While this response is perfectly compliant with the HTTP standard, which provides for the return of documents in a different type if the requested type is not available, it may be a less wise response from a security perspective, as the request suggests a cross site scripting attack is in progress, and the attacker is looking for access to user data from that page.

Most servers correctly returned an error (400 — bad request, 403 — not authorized, or 404 — not found) to our request for a relative URL. However, the 4,759 servers that returned a 200 code were not mostly servers exposing a security vulnerability. Instead, they were mostly configured to return a standard page for any malformed request, not a strict interpretation of the HTTP standard, but not an immediate security risk. For some reason, a 405 (not allowed) response was returned by nearly half the servers for our trace request, rounding out the significant anomalies found in the version codes.

**Unsupported Features.** A number of the features used in our requests seemed simply not to be supported by a majority of web servers. For example, our conditional get, which asked for a page only if it had been modified after a future date, only received the expected 304 response from some 7,000 of the 97,000 responding servers. The remainder simply served up the page, even though the condition had clearly not been met. The actual 501 “Not Implemented” response appeared relatively rarely, with 14,000 servers
returning it for our trace request, and 3,700 returning it for our options request.

3.3 Character Encoding
Not surprisingly, a wide variety of character sets were returned by our servers, with UTF-8 being the most common, followed by ISO 8859-1 and windows-1252. A small portion of servers were obviously misconfigured, returning an empty string or a string such as $conf_pass->charset. We did not develop tests to see if the charsets for the remaining servers matched the actual encoding of the content, but it seems reasonable to assume that additional misconfigurations exist in that space, as well.

More significant is the fact that more than one third of servers (36,000 out of our 100,000) simply did not return a character encoding at all. While correct charset encoding is more important to user experience than to security, several existing security vulnerabilities relate to incorrect or missing character encoding, indicating this is a risk on some deployed servers [19].

3.4 MIME Types
Also interesting from a security perspective is the range of MIME types received. While the responses to our standard GET request were mostly the expected text/html, the responses to some of our other requests had more variety. Responses such as application/java-archive and application/json for an HTML document hinted at server misconfigurations. Significantly, 0.1% of servers returned no MIME type at all, exposing themselves to exploits where an attacker crafts a site to cross-load resources as a different MIME type, thus extracting data from a confidential document.

3.5 XSS Vulnerabilities
One of the more curious MIME type handling behaviors that we observed was in a number of servers that generate the MIME type for their response based not on the actual type of the file, but on the type requested by the client. Indeed, 208 sites in the top 100k, mostly reporting Nginx as their server type, exhibited this behavior. This is a potential vulnerability, as it opens clients to cross-site scripting attacks [19].

In a cross origin CSS attack, an HTML page with confidential information is loaded by a script running from an attacker’s site. If certain short CSS sequences have been injected into the page, the attacker is able to read portions of the secure page. Most browsers, including Chrome, Safari, and Firefox, prevent this by refusing to load files as CSS resources cross origin if they present a conflicting MIME type. However, when asked for a HTML page as CSS, these sites, including sites like kickstarter.com and causes.com which handle sensitive data, report that the HTML page is, in fact, CSS, potentially enabling this sort of attack against their users. While browsers could protect themselves against these attacks by determining a document’s content type through analysis, this behavior represents a significant weakness [2].

4. FUTURE WORK
Our results show that it is possible to gather significant data about a web server and its vulnerabilities based on a few carefully selected HTTP requests. However, there is much room available for further work in refining this process. In particular, additional work is needed to develop a library of requests that are particularly effective at gathering distinguishing information about a server and its security vulnerabilities. Our requests were designed on the basis of informed judgment, but systematic tests with a larger collection of possible requests would likely result in a collection that allowed greater accuracy in predicting server type and in detecting vulnerabilities.

Additionally, our analysis focused primarily on the response codes and MIME types returned from the server. Further research could investigate other details of the server’s response, perhaps finding variations that enable better classification and analysis of the servers studied. Furthermore, ongoing research could survey a broader selection of servers, both less visited servers hosting sites for the general public and the embedded servers found in so many devices.

While our work focused on web servers, and much similar work has been done on general network traffic, there are a broad range of additional Internet technologies where probabilistic techniques could be used to yield a better understanding of software distribution, maintenance, and behavior. This presents many interesting areas for ongoing study.

5. CONCLUSIONS
We have demonstrated that it is possible to predict server type based on server responses, even without a prior analysis of server behavior. This enables a more accurate classification of web server types than would be possible using server version strings alone. It also shows that attempts at security through obscurity by hiding the server version do not provide effective protection to vulnerable web servers. While we were not able to effectively calculate server versions using the technique of analyzing response codes to individual requests, there is no fundamental reason why similar, but more precise, techniques might not also be able to differentiate among versions.

Additionally, even our broad survey, not focused on any particular site or vulnerability, was able to reveal a number of potentially serious configuration issues. This is despite the fact that we focused only on the most visited websites, which would presumably be among the best maintained. Among the misconfigurations observed were improper MIME type configurations that allow a document to be served with no MIME type or with an incorrect type based on the client’s request. Dated server software was also found to be widely in use. The maintenance of a web site is, of course, the responsibility of the site’s owner, but we hope that our research may provide a minor stimulus to raising the profile of the dangers caused by mis-configured server software.

6. ACKNOWLEDGEMENTS
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7. REFERENCES
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Table 8 gives a listing of all of the response strings returned by the top 100,000 servers to our various requests. As can be seen, most of the responses cluster into a few expected categories, but there are large numbers of outliers, including many version codes not defined in the official standard. Even some official codes occurred in surprising places. For example, the IETF defines response code 418 as being an appropriate response from a teapot when instructed to brew coffee [14]. As none of our requests were related to the preparation of hot beverages, it is safe to assume that this code was being used outside of its defined scope.

8. APPENDIX A: RESPONSES FROM SERVERS
| Response Code | Conditional Get | Get FavIcon | Get Relative URL | Get Head | Get HTML as CSS | Options | Partial Get | Trace | Get text as CSS |
|--------------|----------------|------------|------------------|---------|----------------|---------|------------|-------|----------------|
| 0            |                |            |                  |         |                |         |            |       |                |
| 1            |                |            |                  |         |                |         |            |       |                |
| 200          | 88,689         | 73,599     | 4,759            | 95,654  | 94,059         | 91,877  | 80,192     | 95,653| 27,728         |
| 203          |                |            |                  |         |                |         |            |       |                |
| 204          | 3              | 79         | 6                | 3       | 11             | 3       | 10         | 3     | 2              |
| 205          | 1              | 3          |                  |         |                |         |            |       |                |
| 300          |                |            |                  |         |                |         |            |       |                |
| 301          | 2              | 1          | 1                | 2       | 4              | 2       | 3          | 2     | 3              |
| 302          | 1              | 3          | 1                | 1       | 3              | 1       |            |       |                |
| 304          | 6,985          | 1          |                  |         |                |         |            |       |                |
| 400          | 69             | 72         | 66,759           | 70      | 148            | 70      | 385        | 69    | 289            |
| 401          | 26             | 26         | 11               | 26      | 28             | 24      | 271        | 26    | 200            |
| 402          |                |            |                  |         |                |         |            |       |                |
| 403          | 411            | 268        | 16,331           | 410     | 952            | 407     | 1,676      | 409   | 9,492          |
| 404          | 357            | 22,455     | 6,616            | 356     | 540            | 417     | 1,221      | 359   | 1,508          |
| 405          |                |            |                  |         |                |         |            |       |                |
| 406          | 1              | 5          | 6                | 1       | 3              | 3,229   | 39         | 1     | 45             |
| 407          |                |            |                  |         |                |         |            |       |                |
| 408          | 2              | 2          | 3                | 2       | 2              | 2       | 2          |       |                |
| 409          | 1              | 1          | 1                | 1       | 1              | 1       |            |       |                |
| 410          | 1              | 20         | 34               | 1       | 1              | 1       | 1          |       |                |
| 411          |                |            |                  |         |                |         |            |       | 21             |
| 412          |                |            |                  |         |                |         |            |       |                |
| 413          |                |            |                  |         |                |         |            |       | 17             |
| 417          |                |            |                  |         |                |         |            |       |                |
| 418          |                |            |                  |         |                |         |            |       |                |
| 420          |                |            |                  |         |                |         |            |       |                |
| 422          |                |            |                  |         |                |         |            |       |                |
| 429          | 1              |            | 1                | 1       | 1              |         |            |       |                |
| 444          |                |            |                  |         |                |         |            |       |                |
| 499          |                |            |                  |         |                |         |            |       |                |
| 500          | 119            | 146        | 832              | 124     | 253            | 533     | 335        | 122   | 196            |
| 501          | 1              | 8          | 31               | 2       | 3,663          | 14,002  |            |       |                |
| 502          | 53             | 34         | 11               | 53      | 63             | 56      | 87         | 52    | 12             |
| 503          | 88             | 57         | 85               | 87      | 192            | 94      | 158        | 85    | 76             |
| 504          | 10             | 7          | 11               | 12      | 11             | 9       | 10         | 13    | 7              |
| 508          | 2              | 1          | 2                | 1       | 4              | 1       | 1          | 1     | 1              |
| 509          | 1              | 1          | 6                | 1       | 1              | 1       | 1          | 1     | 1              |
| 550          |                |            |                  |         |                |         |            |       |                |
| 599          |                |            |                  |         |                |         |            |       |                |
| 770          | 1              |            | 1                | 1       | 1              | 1       | 1          | 1     |                |
| 801          |                |            |                  |         |                |         |            |       |                |
| 901          |                |            |                  |         |                |         |            |       |                |
| 999          |                |            |                  |         |                |         |            |       |                |
| Totals       | 96,823         | 96,784     | 95,516           | 96,807  | 96,553         | 96,738  | 95,874     | 96,803| 94,586         |

Figure 3: Server response codes from top 100,000 servers by request
## APPENDIX B: APACHE VERSIONS

The following versions of Apache were reported by servers in the Alexa top 100k. A string such as 2.X.X indicates that the server only reported Apache 2, and so on.

| Apache Version | No. of Samples Reported | Release Date   |
|----------------|-------------------------|----------------|
| Apache/1.3.3   | 9                       | 9-Oct-98       |
| Apache/1.3.9   | 2                       | 19-Aug-99      |
| Apache/1.3.11  | 5                       | 21-Jan-00      |
| Apache/1.3.19  | 8                       | 1-Mar-01       |
| Apache/1.3.20  | 40                      | 21-May-01      |
| Apache/1.3.22  | 10                      | 12-Oct-01      |
| Apache/1.3.23  | 26                      | 21-Jan-02      |
| Apache/1.3.24  | 27                      | 22-Mar-02      |
| Apache/1.3.26  | 177                     | 18-Jun-02      |
| Apache/1.3.27  | 265                     | 3-Oct-02       |
| Apache/1.3.28  | 40                      | 16-Jul-03      |
| Apache/1.3.29  | 264                     | 29-Oct-03      |
| Apache/1.3.31  | 180                     | 11-May-04      |
| Apache/1.3.32  | 8                       | Not released   |
| Apache/1.3.33  | 559                     | 29-Oct-04      |
| Apache/1.3.34  | 509                     | 18-Oct-05      |
| Apache/1.3.35  | 19                      | 1-May-06       |
| Apache/1.3.36  | 77                      | 17-May-06      |
| Apache/1.3.37  | 1,223                   | 28-Jul-06      |
| Apache/1.3.39  | 271                     | 7-Sep-07       |
| Apache/1.3.41  | 2,964                   | 19-Jan-08      |
| Apache/1.3.42  | 3,618                   | 2-Feb-08 [EOL] |
| Apache/1.4.0   | 10                      | n/a            |
| Apache/1.4.X   | 100                     | n/a            |
| Apache/1.9.0   | 1                       | n/a            |
| Apache/2.0.4   | 10                      | n/a            |
| Apache/2.0.6   | 10                      | n/a            |
| Apache/2.0.9   | 10                      | Not released   |
| Apache/2.0.35  | 7                       | 5-Apr-02       |
| Apache/2.0.40  | 96                      | 9-Aug-02       |
| Apache/2.0.43  | 10                      | 3-Oct-02       |
| Apache/2.0.44  | 10                      | 20-Jan-03      |
| Apache/2.0.45  | 10                      | 1-Apr-03       |
| Apache/2.0.46  | 270                     | 28-May-03      |
| Apache/2.0.47  | 10                      | 9-Jul-03       |
| Apache/2.0.48  | 20                      | 29-Oct-03      |
| Apache/2.0.49  | 61                      | 19-Mar-04      |
| Apache/2.0.50  | 70                      | 30-Jun-04      |
| Apache/2.0.51  | 144                     | 15-Sep-04      |
| Apache/2.0.52  | 3,107                   | 28-Sep-04      |
| Apache/2.0.53  | 132                     | 7-Feb-05       |
| Apache/2.0.54  | 450                     | 17-Apr-05      |
| Apache/2.0.55  | 348                     | 16-Oct-05      |
| Apache/2.0.58  | 122                     | 1-May-06       |
| Apache/2.0.59  | 1,226                   | 28-Jul-06      |
| Apache/2.0.61  | 204                     | 7-Sep-07       |
| Apache/2.0.63  | 4,858                   | 19-Jan-08      |
| Apache/2.0.64  | 3,804                   | 19-Oct-10      |
| Apache/2.0.X   | 133                     | on or after March 10, 2000 before December 1, 2005 |
| Apache/2.1.X   | 20                      | 1-Dec-05       |
| Apache/2.2.0   | 892                     | 1-Dec-05       |
| Apache/2.2.1   | 10                      | Not released   |
| Apache/2.2.2   | 214                     | 1-May-06       |
| Apache/2.2.3   | 41,012                  | 28-Jul-06      |
| Apache/2.2.4   | 927                     | 9-Jan-07       |
| Apache/2.2.6   | 1008                    | 7-Sep-07       |
| Apache/2.2.8   | 3,443                   | 19-Jan-08      |
| Apache/2.2.9   | 8,635                   | 14-Jun-08      |
| Apache/2.2.10  | 1,401                   | 14-Oct-08      |
| Apache/2.2.11  | 3,270                   | 14-Dec-08      |
| Apache/2.2.12  | 1,126                   | 28-Jul-09      |
| Apache/2.2.13  | 819                     | 8-Aug-09       |
| Apache/2.2.14  | 12,018                  | 3-Oct-09       |
| Apache/2.2.15  | 15,230                  | 5-Mar-10       |
| Apache/2.2.16  | 18,947                  | 25-Jul-10      |
| Apache/2.2.17  | 12,667                  | 18-Oct-10      |
| Apache/2.2.18  | 299                     | 11-May-11      |
| Apache/2.2.19  | 4,108                   | 21-May-11      |
| Apache/2.2.20  | 4,010                   | 30-Aug-11      |
| Apache/2.2.21  | 11,910                  | 13-Sep-11      |
| Apache/2.2.22  | 39,446                  | 31-Jan-12      |
| Apache/2.2.23  | 13,660                  | 13-Sep-12      |
| Apache/2.2.24  | 6,071                   | on or after December 1, 2005 |
| Apache/2.3.5   | 20                      | 26-Jan-10      |
| Apache/2.3.6   | 10                      | 17-Jun-10      |
| Apache/2.3.8   | 28                      | 31-Aug-10      |
| Apache/2.3.11  | 7                       | 7-Mar-11       |
| Apache/2.3.14  | 7                       | 9-Aug-11       |
| Apache/2.3.16  | 6                       | 20-Dec-11      |
| Apache/2.4.0   | 8                       | Not released   |
| Apache/2.4.1   | 182                     | 17-Feb-12      |
| Apache/2.4.2   | 257                     | 17-Apr-12      |
| Apache/2.4.3   | 506                     | 21-Aug-12      |
| Apache/2.4.X   | 40                      | 2012           |
| Apache/2.XX    | 10,891                  | on or after March 10, 2000 |

# of samples reporting version: 238,508