Netwatcher: A Design of an Internet Filter Based on an Adaptive Version of Naïve Bayes

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Abstract

We design an internet content filter named netwatcher based on an adaptive version of Naïve Bayes. Upon interviewing librarians, we found out that overblocking was a major problem with current filters. Netwatcher is designed to reduce overblocking, to place more control in the hands of librarians, and to be more adaptive in terms of retraining the learning algorithm. The filter is divided into three parts: the learning algorithm, a list of pre-defined block sites, and an online community of clients that can update each other.

Thesis

This paper shows that a filter design based on an adaptive version of Naive Bayes, a learning algorithm, is an effective solution for libraries wishing to receive E-rate and LSTA funding. The filter will serve as a text classifier differentiating between material that is either patently offensive, harmful to minors, or both, and material that is not. Librarians will benefit from using this design because it reduces the over blocking of sites that are not patently offensive, grants librarians more control over the process of blocking sites, and takes the input of librarians into account for improving the filter

Table of Contents

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1.0 Introduction

1.1 Overview

With the advent of the internet, ordinary people have gained the ability to access a wealth of material very easily. Such a wealth of material forms the content of the internet, and is as diverse as human thought [1]. It ranges from educational material to purely pornographic material. Parents seeking to protect their children from objectionable material have generally opted for internet filters. Internet Filters uses certain algorithms to detect certain material online and prevent computer users from accessing such material. No filter is as good as human judgment; as a result, there is still a lot of work to be done in improving current filters.

This paper aims at proposing the design of a viable internet filter that specifically meets the needs of librarians seeking E-rate and LSTA funding. In designing an effective filter tailored to the need of librarians, there are several requirements that the filter must meet:

- The filter must never remove control from librarians. Instead, it must place more control in the hands of librarians
- The filter must reduce overblocking
- The filter must be adaptive through the use o fits responsiveness to librarians.

The design seeks to meet all three criteria. The design does not seek to create a filter that prevents access to all sorts of user communication. It does not behave similar to a firewall; it does not seek to filter incoming nor outgoing telnet and ftp connections.

1.2 Legal Background

In response to mounting concerns that children would be exposed to objectionable material, Congress passed a series of legislation that placed restrictions on internet use in order to protect minors, including the Communication Decency Act (CDA) [2], the Child Online Protection Act (COPA) [3], and Child Internet Protection Act (CIPA) [4]. However while relevant portions of both the CDA and COPA were struck down by the U.S. Courts in *Reno v. ACLU* [5] and in *ACLU v. Ashcroft* [6], CIPA was upheld as constitutional by the Supreme Court in the in *United States v. American Library Association* [7]. Applying a rational basis review, Chief Justice Rehnquist and three other justices pointed out that the government had a legitimate interest in protecting minors from inappropriate material, public libraries had broad discretion to decide what material to provide to their patrons, and that patrons who are adults could ask the librarian to unblock erroneously blocked sites or disable the filter completely.

The provisions of CIPA state that public libraries or schools wishing to receive federal assistance must install and use technologies for filtering or blocking material on the Internet for all computers with Internet access. The two types federal assistance which are adversely affected by CIPA is the E-rate program [8], which allows libraries to buy Internet access at a discount and Library Services and Technology Act [9] , LSTA, which assists libraries in acquiring computer systems and telecommunication technologies. The three types of material CIPA seeks to protect minors from are visual depictions that are obscene, that contains child pornography, or that are harmful to minors.
Obscenity as defined by three prong test established in Miller v. California [10] and codified in 18. U.S.C. 1460 (2003) [11] is:

- Whether the average person, applying contemporary community standards, would find that the material, taken as a whole, appeals to the prurient interest;
- Whether the work depicts or describes, in a patently offensive way, sexual conduct specifically defined by the applicable state or federal law to be obscene; and
- Whether the work, taken as a whole, lacks serious literary, artistic, political, or scientific value.

The definition of child pornography is stated in 18 U.S.C. 2256 (2003) [12] as any visual depiction of a minor under 18 years old engaging in sexually explicit conduct, which includes actual or simulated sexual intercourse, bestiality, masturbation, sadistic or masochistic abuse, or "lascivious exhibition of the genitals or pubic area. In *Ashcroft v. Free Speech Coalition* [13], the U.S. Supreme Court ruled that any activity not actually involving a minor cannot be child pornography. The definition harmful to minors is stated in CIPA as:

- Any picture, image, graphic image file, or other visual depiction that taken as a whole and with respect to minors, appeals to a prurient interest in nudity, sex, or excretion;
- Any picture, image, graphic image file, or other visual depiction that depicts, describes, or represents, in a patently offensive way with respect to what is suitable for minors, an actual or simulated sexual act or sexual contact, actual or simulated normal or perverted sexual acts, or a lewd exhibition of the genitals; and
- Any picture, image, graphic image file, or other visual depiction that taken as a whole lacks serious literary, artistic, political, or scientific value as to minors.

1.3 Current Solutions

Even though CIPA states that only material that is obscene, that contains child pornography or that is harmful to minors should be blocked, companies that build internet filters often block other material that does fit into the criteria. This "overblocking" occurs because filtering software manufacturers often inject their subjective biases in determining which site is objectionable. Whereas a filtering software manufacturer might not block material by the Ku Klux Klan because it sees it as primary source material in the context of a research report about the history of the American south, another filtering software manufacturer may see the material as hate speech. Similarly, many currently available filters block materials pertaining to internet chat rooms, criminal skills, drugs, alcohol, tobacco, electronic commerce, free pages, gambling, hacking, hate speech, violence, weapons, web-based email, and more. These categories are not included under the legal definition of CIPA [14].

Another factor causing overblocking is that filtering software manufacturers use simple and relatively non-effective algorithms to determine which sites should be blocked. Most commercially available filters ‘remember’ the web page Uniform Resource Locators (URL) of sites deemed inappropriate, however many times they block all the available pages of a site when those pages do not contain any objectionable material. PICS [define the acronym], a voluntary self-rating system of evaluating websites, has eased the job of filtering internet content, however it still remains voluntary their use is limited to a certain number of the websites out on the Internet.[15] . Table One contains the details of the filtering techniques employed by eleven of the most commonly available filters.

	A+ Inernet Filtering	Bess	ChiBrow	Child Safe	Cyber Patrol	CYBER-sitter	ADL	The Internet Filter	IPrism	Net-nanny	Safe Access
Web page URL	Y	N	Y	Y	Y	Y	N	Y	Y	Y	Y
List of keywords	Y	Y	Y	N	Y	Y	N	Y	N	Y	N
Analysis of context in which keywords appears	N	Y	Y	N	N	Y	N	Y	N	Y	Y
PICS rating	N	N	Y	N	Y	Y	N	N	N	Y	N
Human review of websites	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y

Table 1: Current Filtering Techniques: This is table detailing the techniques employed by eleven of the most commonly used filters in order to determine whether should be blocked or whether a site should be allowed. Each of these techniques has their own strengths and weaknesses [16].

Although it is difficult to accurately discern the number of sites that are overblocked either due to subjective decisions or technological failures, the Electronics Frontier Foundation estimates that for every web page blocked as advertised, filters blocks one or more web pages incorrectly [17]. In terms of numbers, this is close to 10,000 sites minimum when the filters are placed in the least restrictive [18]. In another independent expert report, Ben Edelman of Harvard University noted that 6,777 sites were improperly blocked by four different filters, Surfcontrol Cyber Patrol 6, N2H2 Internet Filtering 2.0, Secure Computing SmartFilter 3.0, and Websense Enterprise 4.3. [19].

More important than the number of sites that are blocked, are the types of sites that are blocked. The Electronics Frontier Foundation reported that N2H2's Bess, one of the most popular filters available, blocked a page describing community partners of the Mary Street School [20]. Similarly, the Boston Globe reported that Netnanny, which is used by the Kingston Public Library, blocked access to blocked access to a Massachusetts Board of Library Commissioners website page that explains CIPA [21]. In the fall of 2003, we spoke to various local libraries around Boston, Cambridge, Everett Medford, Malden, Somerville, and Revere to confirm these results.

To address the problem of overblocking, filter software manufacturers have incorporated a variety of features. While many commercially available filters do not allow users to review the list of URLs that are blocked, they generally allow users to review the list of keywords or the company's criteria for filtering a webpage. Some also allow users to edit the categories which are

blocked, permanently edit or completely override the filtering software's list of material to be blocked, or create their own block list either from scratch or by starting with the manufacturer's list. Table Two describes the available customization features in commonly used filters.

	A+ Inernet Filtering	N2H2 Bess	ChiBrow	Child Safe	Cyber Patrol	CYBER - sitter	ADL	The Internet Filter	IPrism	Net-nanny	Safe Access
Filter software manufacturer alone decides what material will be filtered	Y	N	N	N	N	N	N	Y	N	N	Y
Users can review the list of keywords	Y	N	Y	N	Y	N	N	Y	N	Y	N
Users can review the list of filtered web page addresses	N	N	Y	N	N	N	N	Y	N	Y	N
Users can review the company's criteria for filtering a web page	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Users are able to chose from pre-set categories what material they want to filter	N	Y	Y	Y	Y	Y	N	Y	Y	N	Y
Users are able to permanently edit the company's list of material to be filtered	N	N	Y	Y	Y	N	N	Y	Y	Y	N

Users are able to completely override the company's list of material to be filtered	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Users are able to develop their own list of information to be filtered, using the manufacturer 's list as starters	N	N	Y	Y	N	N	N	Y	N	Y	N
Users are able to develop their own list of materials to be filtered, starting from scratch	N	N	Y	Y	N	N	N	Y	Y	Y	N

Table 2: Customization Tools: This is table detailing the customization tools that are available on eleven of the most popular filters. They allow users to individually tailor the filter to suit their needs, however many of the features take a considerable amount of time and are not so easy to use [22].

Instead of engaging in these relatively time-consuming and not-so-easy customization tactics, many libraries have sought to avoid filters completely. At Lynn Public Library, for instance, librarians have adopted an informal tap-on-the shoulder policy whereby if someone is looking at inappropriate material, a librarian will usually approach that person [23]. In Nahant, librarians are only able to conduct the search one computer that is connected to the internet and staff patrons are not allowed to access the web [24]. Clearly however, these 'alternative' measures are not in compliance with CIPA, and come at the cost of losing E-rate and LSTA funding, which many libraries could desperately use [25].

2.0 Design Solution

2.1 Design Overview

Internet content filtering is very similar to email spam filtering in many respects. Currently, most email spam filters are employing machine learning algorithms to learn about the attributes of email that can be categorized as spam. After learning about the attributes, the algorithms will

classify future email as spam or not based upon the learned attributes. Internet content filtering should be a very similar process. In essence, internet filters should aim at being able to classify text --- in this case content of sites – as filterable or not. Filterable in this case refers to material that is either harmful to minors, obscene, or contains child pornography [26]. As a result, a similar exploitation of machine learning algorithms would greatly enhance the capability of internet content filters.

Although the law, CIPA, is mainly concerned with filtering visual depictions and images, most pornographic sites usually contain erotic stories and certain "linguistic description" of images [27] . In fact in the paper, Marketing Pornography on the Information Superhighway, the classification scheme that was used to classify images relied heavily on the verbal descriptions. The study concluded that the verbal descriptions of sexually-explicit images are carefully worded to entice consumers.

Netwatcher seeks to build on the concept of utilizing machine learning algorithms. The design consists of three basic parts: (1) a Naïve Bayes learning algorithm specifically trained to classify text as filterable and not, (2) a list of pre-defined blocked sites that has priority over the learning algorithm, (3) and an online community of clients that can intercommunicate and whose actions of blocking and unblocking of sites are recorded as data to further train the learning algorithm. The paper delves a bit more into each part in the next three sections.

As designed, the filter will serve as an intermediary between web browsers and the internet. It will effectively listen for both incoming and outgoing messages. It will screen out both the messages that originate from sites that are blocked and user request for information that is available on the blocked sites. It will run the algorithm on the incoming messages before forwarding them to the web browsers. Figure One contains a diagram of where the filter is situated.

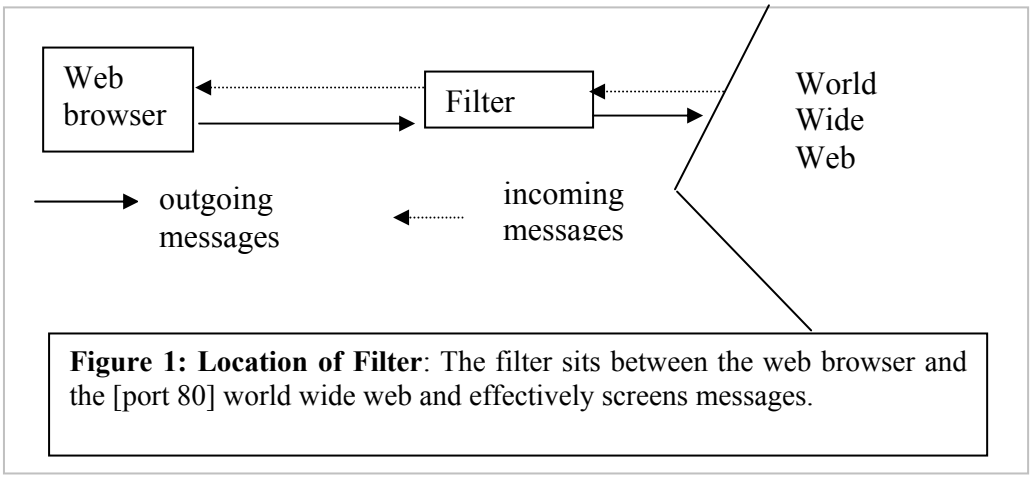

Figure 1: Location of Filter: The filter sits between the web browser and the [port 80] world wide web and effectively screens messages.

Each library will have a list of predefined blocked sites. This list is determined by each librarian. If upon reviewing a site, a librarian has deemed the site filterable, then the librarian can choose to add the site to the list of blocked sites. If upon further review, the librarian felt mistaken about her judgment, she can remove the site from the list of blocked sites. The list of predefined blocked

sites is given priority over the learning algorithms. Before classifying a site, the filter will explicitly check to see whether or not the site is not already in the list of predefined blocked sites. If it is, it will be blocked. If it is not, then algorithm will classify it and filter it based upon the classification.

The online community will consist primarily of filtering clients and data storage servers. Each individual library will represent a client. The clients will communicate with each other. The clients may choose to be updated whenever a library has chosen to block or unblock a site. The client may even choose to be updated when fifty percent of all clients have chosen of block a site, or simply never to be updated. The client must however update the servers will all of the information that it is blocking or unblocking.

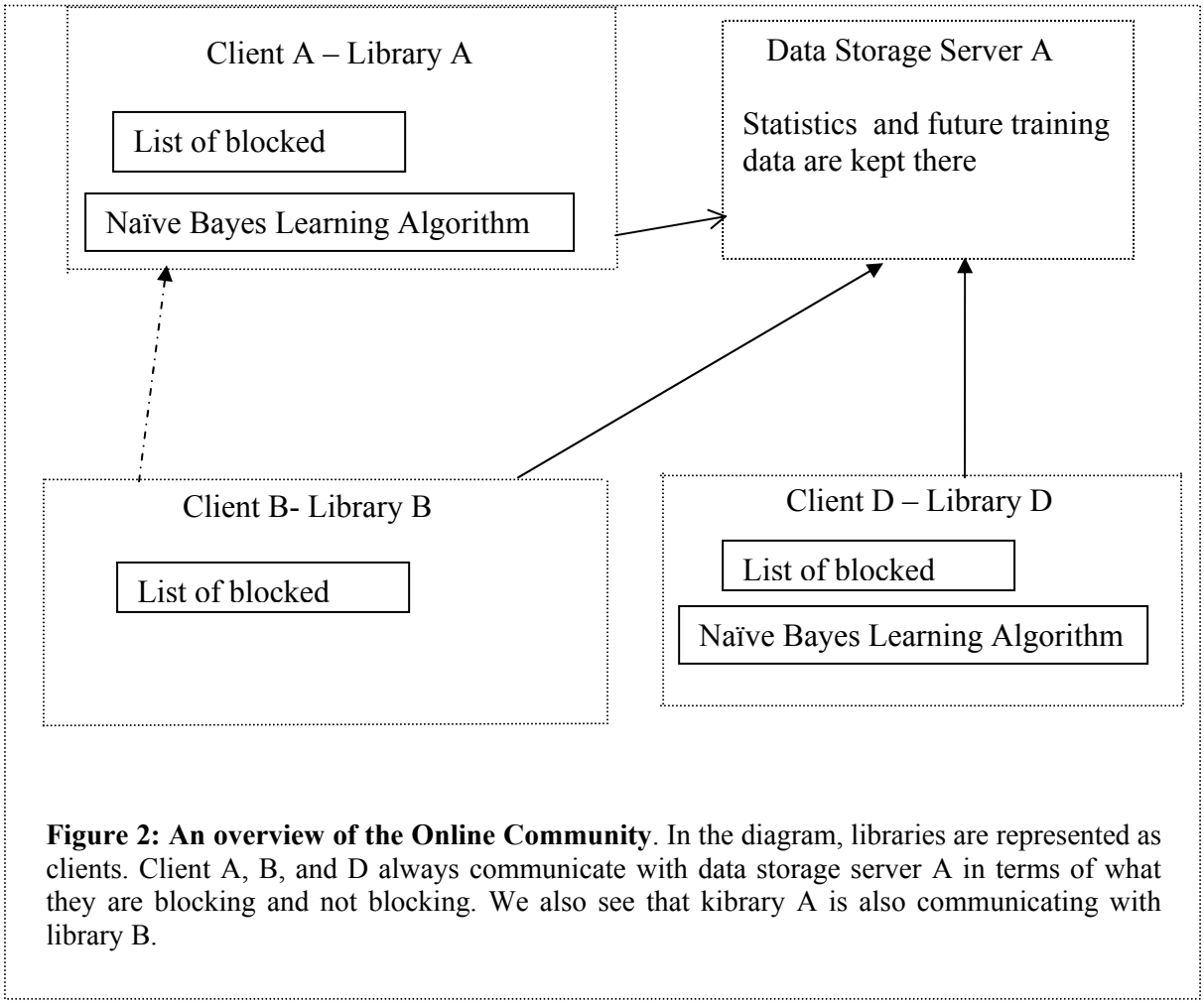

Figure 2: An overview of the Online Community. In the diagram, libraries are represented as clients. Client A, B, and D always communicate with data storage server A in terms of what they are blocking and not blocking. We also see that kibrary A is also communicating with library B.

2.2 Design Descriptions

2.2.1 Naïve Bayes as the algorithm of choice

Naïve Bayes is the algorithm of choice because of its simplicity and efficiency in terms of working with large amounts of data. Many email spam filter are using Naïve Bayes and it has proven to be a successful tool in learning the attributes of spam. As we have mentioned earlier, internet content filtering is similar to email spam filtering. It applies even in our case, where the government is concerned with mainly filtering out visual depictions of pornography because most pornographic websites usually contain many written depictions along erotic stories. In fact in the paper, Marketing Pornography on the Information Superhighway, the classification scheme that was used to classify images relied heavily on the verbal descriptions [27].

Naïve Bayes works by making predictions based upon the available information. The predictions are called inferences. The inference of a category is an inverse transition from evidence to hypothesis. [28]. Given a set of documents, in our case web pages, one is aiming at classifying these documents. If one has a predefined set of documents that have been classified, one can reduce the classification problem to simply matching the similarities in documents. The documents contain words and these words will serve as the evidence we need in our feature space. The hypothesis will be to determine the proper classification of the documents. In simple terms, Bayes algorithm states that (1) one should update the probability of a hypotheses based on evidence, and (2) one should choose the hypothesis with the maximum probability after the evidence has been incorporated [6.034 lecture notes].See Appendix A, for a more thorough description of Naïve Bayes.

Using a Naïve Bayes approach, the classified documents can be screened for all the words contained in them and the probably that these words occur in each category of documents. For example, if we were to classify each document with a one or zero with one denoting good and zero denoting bad. Then each word can take the value of one in which case a one would indicate the presence and zero would the absence of a word in given document. Supposing that there are only three words in all the documents, then the document in the table below can represent a possible set of classified documents.

Documents	First World	Second Word	Third Word	Document classification
First Document	0	1	1	0
Second Document	1	1	0	0
Third Document	1	0	1	0
Fourth Document	1	0	1	1
Fifth Document	0	0	1	1

Table 3: Classification Table : This is table containing classifications for three documents containing only a possible of three words. The document can be classified as a zero (bad) or a one (good). A zero for word indicates that it is nor present in the document, whereas a one implies that it is present.

According to the table, two documents are classified as a one and three are classified as zeroes. Out of the documents classified as ones, the first word has a probability of one half of being present, and one half of being absence. For the probability of being present for the documents classified as zero, let's call Pji the probability that word j is present in all documents specified as i. Similarly, if Aji is the probability of a word being absent in all documents classified as i. Then Aji is the equivalent of 1 – Pji. In our example, P11 is ½ and A11 is also ½. P10 is 2/3 and A10 = 1/3.

Suppose one wanted to classify a document that contained word one but not word two nor word three from the classification table. According to Naïve Bayes, in order to determine the likelihood of the document being classified as category I, then one needs to multiply the probabilities Pji or Aji for each word based upon whether or not the words are present are absent in the document. In our given document we would multiply P11 by A21 and A31, to determine the likelihood of document falling into category one. To determine the likelihood of it falling into a category zero, one would multiply P10 by A20 and A30. The algorithm would classify the document by choosing that category containing the higher likelihood. In classifying the first document, the inference probability of the document being a one can be obtained throught the product of A11, P21 and P31, which result in a half multiplied by zero and by 1. The result would be zero. The inference probability of the document being a zero would be the product of A10 , P20, and P30, which result in The result would be four thirds.

On a different note, in order for Naïve Bayes to work properly we need to implement a simplified version of a page rank algorithm. [explain what you mean by a page rank algorithm, and how it solves the problem of multiple pages on the site] One can not simply tell whether or not a website is harmful to minors based upon the content of only the first page of the website. As a result, we have chosen to also classify the links to other pages on the webpage to a depth of two. The obvious scenario is the scenario in which there is an entrance page to a pornographic site. The entrance page will not be the sole indicator in determining whether or not the site should be filterable.

2.2.2 Applying Naïve Bayes

As explained above, we implemented the algorithm in a similar fashion.
The goal was to classify websites as either filterable or not filterable, where the category of filterable meets the criteria of being obscene, harmful to minors, pornographic, or all three. Websites that should be filtered were classified as ones and websites that should not be filtered were classified as zeroes. The words contained in the websites were used as the evidence.

In determining the set of words that should be included in the word space, all two-letter words were eliminated. Most two-letter words do not add much meaning to the written descriptions and erotic stories posted by pornographic websites. As a result the words on the feature space do not correspond to a one to one mapping of words that are available in ordinary dictionary. Furthermore, many pornographic websites contain words that do not form part of ordinary usage. These words include "jizz", "skank", and "smut."

Given the fact that many inappropriate websites contain entry pages that require users to click on enter before proceeding to the site, it was decided that one page of a website can not properly classify the website itself. As a result, the classification of a page entailed also classifying its links to degree of two for the training set. However, for reasons of efficiency, we restricted the classification of documents to also classifying their links to a degree of one.

The version of Naïve Bayes used was also an improved version. It implements the Laplace correction, which entails correcting the fact that the likelihood of a document falling into a category will be zero when a word is not present in the document. If a word is not present in the document, its inference probability will be ½ according to the Laplace corrections. Intuitively, this correction makes sense because the fact that a word is absent from a document should not give any added information. This changes the calculations of the classification table above because it guarantees that Since the feature space is extremely big, the likelihood calculations will reduce to calculating very small probabilities. In order to simply the calculations, the logarithmic function is applied to the product of the inferences. The result is a summation of the logs of each individual inferences.

2.2.3 Implementing Naïve Bayes

In order to fully implement Naïve Bayes, one needed an exhaustive set of training data. To obtain the training data, the members of we crawled through over a thousand websites. These websites were ranked as filterable and not filterable. In ranking the websites, we sought to explore as many links as possible in order to not solely rank a page of the website. After ranking the websites, we compiled a list of URLs followed by their ranking of a zero or a one.

In order to develop the feature space, we compiled a list of words that was used in the training set along with their frequency of usage in the two different categories of websites. The feature set excluded two-letter word. Note that there does not need to exist a one to one mapping between the features in the feature space and the words in a normal English dictionary. Whereas a normal English dictionary's word space will contain words such as 'to', 'be', and 'as', these words will be inconsequential to our design. Popular research has indicated that most two-letter words are inconsequential in conveying the meaning of text. Furthermore our feature space will contain possible combination of letters such as 'skank', 'jizz', and 'smut' because they commonly appear in sites that harmful to minors .[29].

2.3 The Predefined Block List

Every filter comes with an empty predefined block list. The list should contain a listing of sites that a librarian has deemed filterable. Librarians can remove or add sites to the list. The algorithm works by checking to see if any users are requesting to view a site in the blocked list. This is done by listening to the outgoing requests that going through port 80. If a user is attempting to view a site on the blocked list, then the filter will respond with a message stating that the site has been blocked.

2.4 The Online Community

2.4.1 The Clients

The online community consists of filtering clients and data storage servers. The libraries the clients and they can communicate with each other. The data storage servers will be pre-established center for data collection. All clients must update a number of the servers when they have chosen to block or unblock a site. Clients can do any of the following:

(1) choose to be updated or not about other clients' actions.
(2) choose to be updated whenever a library has chosen to block or unblock a site.
(3) choose to be updated when a certain percentage of clients have blocked a site.

2.4.2 The Data Storage Servers

The data storage servers serves as training data aggregation centers. They compile statistics on each client's behavior. They systematically present each client with more data to train and improve the algorithm. They also systematically update the clients with a list of addresses of all the servers. The storage servers continually listen for incoming requests from clients, or check to see if a certain condition has been met to warrant updating a client.

In order to achieve reliability the data storage servers will replicate the data on the client's blocking and unblocking actions among themselves. At midnight, every day, the servers will update other servers with certain data taken from a certain interval of time from a certain set of clients. The other servers will check to see if they already contain such data. If they do, they will not copy it. If they don't, they will copy the data.

2.4.3 Client-Server Interaction

Clients interact with servers in two ways: (1) by making a request to the servers to be updated or (2) by receiving update messages from the servers. Request messages are of the type "please notify me when 50% of libraries have blocked a site." Update message will be of the types "Here is the latest training data, train the algorithm," or "here is list of addresses of all the servers.

The client to server ratio will remain at 150 clients per server and each client will be assigned three servers that it can make requests to. In the event that one of the servers is down, the client will be able to make a request to another server. In order to achieve reliability, each server will periodically update the clients with a complete list of addresses of all the servers. In the event that all three of a client's assigned servers are down, the client will be able to contact another server.

2.5 Simulations

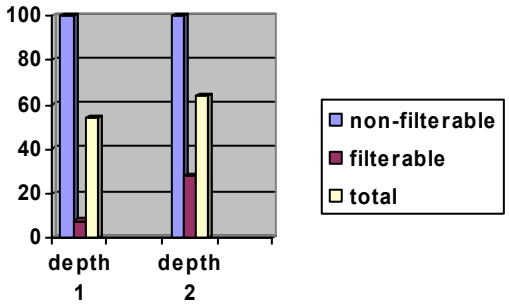

Figure 3: Chart displaying percentage of correctness. The chart indicates the percentage of each category that was properly classified.

We classified 50 websites after the first round of training the algorithm for a depth two and depth one analysis. Half of those websites should have been filtered and half should not have been filtered. Figure Three contains the actual percentages of sites that were properly classified. For the most part the filter never overblocked sites, but it did underblock a number of sites. After the algorithm was retrained with added data, fifty more websites, it did not improve significantly. The only key difference to note was that the algorithm performed better with a depth of teo analysis. We can attribute such underblocking to the cleverness of most pornographic sites

webmasters. Most of the pornographic sites that we analyzed contained very little text. Furthermore, the ones that Contained text embedded the text in images.

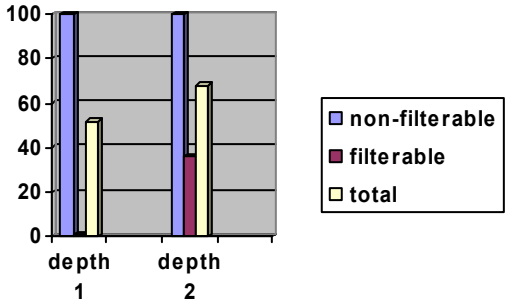

Figure 4: Chart displaying percentage of correctness. The chart indicates the percentage of each category that was properly classified after the training data was modified with extra data.

3. Feasibility

In designing netwatcher, there were many design tradeoffs that were made. These tradeoffs range from depth of the websites that we chose to analyze to what type of blocked list mechanism would be in line with a liberal filtering policy. This section will elaborate on some of those tradeoffs.

A primary goal of netwatcher was that it would improperly classify sites. We wanted it to reduce the problem of overblocking, but however not overly increase the problem of underblocking. As a result, out first aim was to fully classify each website well by analyzing it to a depth of two, meaning that we also classified the outgoing links of the website and those outgoing links' respective outgoing links also. However, we found that this method was rather inefficient and slow; it did not add much more information from a depth one analysis. As a result, we decided to go with the depth two analysis.

In training the algorithm, the original goal was to use as much data as possible; we settled for compiling 2,000 sites along with human ratings of those sites. This goal was not feasible given the time length of this project and the fact that analyzing 2,000 sites to a depth two would have required a considerable amount of human time. Furthermore, this number had to be reduced due to computer memory limitations and the number of hours it took for a depth of two analysis. A depth one analysis took quite some time as well, because most pornographic sites contain a great deal of links. The number of sites was reduced to a 1,000 with roughly forty percent consisting of material that should be filtered.

In blocking a site, it is not as simple as simply blocking the entire URL nor as simple as simply blocking an entire domain. For example, in blocking the URL "http://web.mit.edu/www/jean/stuff/morestuff/page.html," the aim would not be to block simply page.html because that will lead to gross underblocking. If update.html is in the directory 'morestuff', then it will not be blocked and most likely the content of it will form part of the website containing page.html. However, blocking the domain web.mit.edu will lead to gross overblocking. As a result, the compromise that was reached was to block the entire directory 'morestuff'. The reasoning is that even though the blocked list in the control of users, the

algorithm implements a liberal filtering policy. It aims to sacrifice to always sacrifice not overblocking at the risk of underblocking. In the example, the parent directory might also be a part of the web site, however it would wrong to block if it is not a part of the website.

4. System Evaluation

This section analyzes whether a filter based on Naïve Bayes is viable and will be widely adopted. In particular, this section will examine the four major forces that have influence behavior in today's world: law, architecture, market, and norms.[1]

4.1 Law

In order to be in compliance with CIPA, a library must install any technology protection measures that protect against access to material that is obscene, child pornography, or harmful to minors, and also must enforce the operation of such technology measures. By its broadest definition, a filter based on Naïve Bayes achieves these goals: only material that was patently offensive, child pornography, and harmful to minors was blocked, and libraries had the ability to update the information on the filter.

If Congress is able to successfully reenact the CDA, COPA, or any other legislative measure that places restrictions on what can be published, any filtering technology obviously becomes obsolete. However, given Supreme Court has held that filtering is a less restrictive alternative in both *Reno v. ACLU* and *ACLU v. Ashcroft*, and given that we have shown that filter based on Naïve Bayes can be an extremely effective alternative, barring any major developments, the burden of protecting children will continue to be placed on the receiving end rather than the sending end.

4.2 Architecture

Because it is designed to automatically block objectionable material, a filter based on Naïve Bayes has significant advantages over self rating schemes. For instance, self-rating schemes often cause controversial sites to be censored because if the operators of these sites choose rate these sites, they will be lumped with 'pornography' and therefore blocked, however if the operators of these sites choose not to rate these sites, they will be considered 'unrated' and also blocked. In contrast, the only sites that a filter based on Naïve Bayes blocks are those that are obscene, child pornography, and harmful to minors. In addition, self-rating schemes also have possibly adverse effect on the democratic nature of the internet, since commercial speakers will be able to better deal with the burdens associated with self-rating systems in comparison to non-commercial and individual speakers. Comparatively, our filter seeks to preserve the structure of the internet.

Because current filters are relatively ineffective, self-rating schemes have still enjoyed immense popularity despite these problems. By showing that a filter based on Naïve Bayes, the hope is that people will be inclined to adopt the solution that provides protection to children, but also does not place an undue burden on publishers.

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[1] Lessig, Larry, 1999. "The Law of Horse: What Cyberlaw might teach" [online]. Cambridge, MA, Harvard Law Review [updated 1999, cited 8 December 2003]. Available from World Wide Web: (http://www-swiss.ai.mit.edu/classes/6.805/articles/lessig-horse.pdf).

4.3 Market

As mentioned in the introduction, CIPA merely provides federal assistance to libraries that employ filters or other technology protection measures that protect against access to material that is obscene, child pornography, or harmful to minors. If libraries choose to implement filters, they will receive these federal funds. If they choose not to, their only punishment is that they do not receive these funds.

Despite the financial difficulties facing libraries, many libraries have still continued to resist the use of filters because filters block Constitutionally-protected speech and because libraries do not have control over the sites that filters block. By addressing these concerns through the creation of a filter based on Naïve Bayes, many libraries in dire need of funding may reconsider the use of filters.

4.4 Norms

Even though it is designed to automatically only blocks material that is patently offensive child pornography, and harmful to minors, the filter implemented in this paper also takes into consideration community standards through the predefined block list which is shared with other libraries. For one thing, certain libraries might believe that hate speech should be censored. Not only does our particular filter allow hate speech to be censored, it also allows all libraries who are against hate speech to assist each other in blocking sites with hate speech. At the same time, when a library blocks a sites that many others would not believe should be blocked, other libraries will become aware that a site that probably should not be blocked is being blocked.

Obviously, the filter implemented in this paper is not perfect in the sense that a library in an isolated community could theoretically block a site that nobody else would block. However, the ability for libraries to individually tailor their block list in a relatively efficient manner is still compelling reason for libraries to implement our particular filter.

5.Conclusion and Future Recommendations

Netwatcher has established its goal of reducing overblocking, however on the other hand underblocking is also drastically increased. Part of the reason for this is the fact that most pornographic sites contain very little text and that the ones that contain text embeds it in the images. We should also say that a little refining of our feature space would have probably helped also. Nonetheless, netwatcher contains its strengths and weaknesses. It is only through the improvement of the weaknesses that the overall filter will improve.

Netwatcher's weaknesses include its inability of being able to automatically block mirrors of websites that are on its predefined list of blocked sites. It is particularly hard to determine whether or not a site is a mirror of another site. One possible way might be with the introduction of a threshold percentage of similarity. One could say that website A abd website B are if mirrors if and only if their contents match up 85% correctly. Content matching would entail similarity of directory structures and file to file content matching and dates of modifications. However, this solution exacerbates the lag that users will experience in retrieving information from the world wide web.

Netwatcher can also be improved through the use of image classification instead of text classification. Webmasters of pornographic sites can easily update their site to include text only images, which would defeat the entire purpose of netwatcher as a text classifier. In the future, it might be good to implement the filter a a complete image classification tool given CIPA's constraints.

6.References

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3. Child Online Privacy Act (47 U.S.C. 231 (2000))

4. Children Internet Protection Act (20 U.S.C. 9134(f) (2000))

5. *Reno v. ACLU* (521 U.S. 84 (1997))

6. *ACLU v. Ashcroft* (322 F. 3d 24 (2003))

7. *United States v. American Library Association* (123 S. CT. 2297; 156 L. Ed. 2d 221 (2003))

8. E-rate funding is adversely affected. (47 U.S.C. 254(h) (2003))

9. LSTA funding is also inversely affected. (20 U.S.C. 9101 (2003))

10. Miller v. California, 413 U.S. 15 (1973)

11. 18. U.S.C. 1460 (2003)

12. 18 U.S.C. 2256 (2003)

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[24] Ibid.

[25] Ibid.

26 United States v. American Library Association, 123 S. Ct. 2297, 156 L. Ed. 2d 221 (2003)

27 [Marketing Pornography On the Information Superhighway] http://www-swiss.ai.mit.edu/6805/articles/pornscare/rimm-study/mrtext.html

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29. see 27

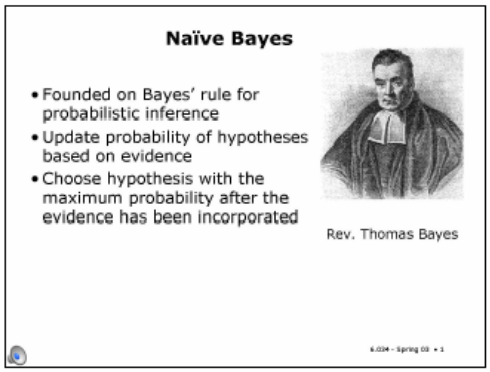
7.0 Appendix

Appendix A: Description of Naïve Bayes

Excerpt taken from 6.034 (Introduction to Artificial Intelligence) lecture note.

6.034 Notes: Section 9.5

Slide 9.5.1
Let's look at one more algorithm, which is called Naive Bayes. It's named after the Reverend Thomas Bayes, who developed a very important theory of probabilistic reasoning.



Naïve Bayes

- Founded on Bayes' rule for probabilistic inference
- Update probability of hypotheses based on evidence
- Choose hypothesis with the maximum probability after the evidence has been incorporated

Rev. Thomas Bayes

- Algorithm is particularly useful for domains with **lots** of features

6.034 - Spring 03 • 2

Slide 9.5.2
It's widely used in applications with lots of features. It was derived using a somewhat different set of justifications than the ones we've given you. We'll start by going through the algorithm, and at the end I'll go through its probabilistic background. Don't worry if you don't follow it exactly. It's just motivational, but it should make sense to anyone who has studied basic probability.

Slide 9.5.3
Let's start by looking at an example data set. We're going to try to characterize, for each feature individually, how it is related to the class of an example.

First, we look at the positive examples, and count up what fraction of them have feature 1 on and what fraction have feature 1 off. We'll call these fractions $R_1(1, 1)$ and $R_1(0,1)$. We can see here that most positive examples have this feature 1 off.

Example

f_1	f_2	f_3	f_4	y
0	1	1	0	1
0	0	1	1	1
1	0	1	0	1
0	0	1	1	1
0	0	0	0	1
1	0	0	1	0
1	1	0	1	0
1	0	0	0	0
1	1	0	1	0
1	0	1	1	0

- $R_1(1,1)$=1/5: fraction of all **positive** examples that have feature 1 **on**
- $R_1(0,1)$=4/5: fraction of all **positive** examples that have feature 1 **off**

6.034 - Spring 03 • 3

Example

f_1	f_2	f_3	f_4	y
0	1	1	0	1
0	0	1	1	1
1	0	1	0	1
0	0	1	1	1
0	0	0	0	1
1	0	0	1	0
1	1	0	1	0
1	0	0	0	0
1	1	0	1	0
1	0	1	1	0

- $R_1(1,1)$=1/5: fraction of all **positive** examples that have feature 1 **on**
- $R_1(0,1)$=4/5: fraction of all **positive** examples that have feature 1 **off**
- $R_1(1,0)$=5/5: fraction of all **negative** examples that have feature 1 **on**
- $R_1(0,0)$=0/5: fraction of all **negative** examples that have feature 1 **off**

6.034 - Spring 03 • 4

Slide 9.5.4
Now, we look at the negative examples, and figure out what fraction of negative examples have feature 1 on and what fraction have it off. We call these fractions $R_1(1, 0)$ and $R_1(0, 0)$. Here we see that **all** negative examples have this feature on.

Slide 9.5.5
We can compute these values, as shown here, for each of the other features, as well.

Example

f_1	f_2	f_3	f_4	y
0	1	1	0	1
0	0	1	1	1
1	0	1	0	1
0	0	1	1	1
0	0	0	0	1
1	0	0	1	0
1	1	0	1	0
1	0	0	0	0
1	1	0	1	0
1	0	1	1	0

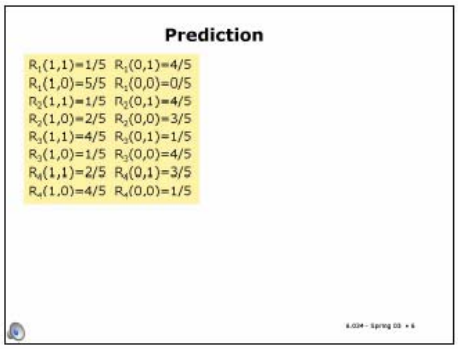
$R_1(1,1)$=1/5 $R_1(0,1)$=4/5
$R_1(1,0)$=5/5 $R_1(0,0)$=0/5

$R_2(1,1)$=1/5 $R_2(0,1)$=4/5
$R_2(1,0)$=2/5 $R_2(0,0)$=3/5

$R_3(1,1)$=4/5 $R_3(0,1)$=1/5
$R_3(1,0)$=1/5 $R_3(0,0)$=4/5

$R_4(1,1)$=2/5 $R_4(0,1)$=3/5
$R_4(1,0)$=4/5 $R_4(0,0)$=1/5

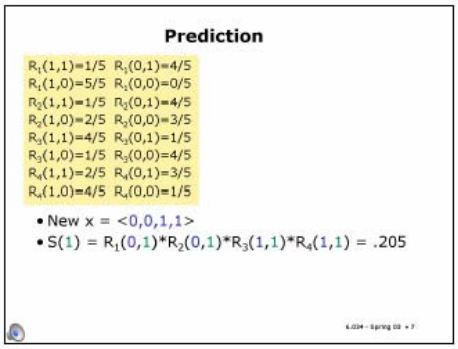
6.034 - Spring 03 • 5

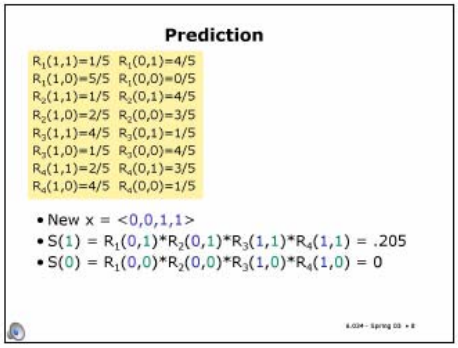


Slide 9.5.6
These R values actually represent our hypothesis in a way we'll see more clearly later. But that means that, given a new input x, we can use the R values to compute an output value Y.

Slide 9.5.7
Imagine we get a new x = <0, 0, 1, 1>. We start out by computing a "score" for this example being a positive example. We do that by multiplying the positive R values, one for each feature. So, our x has feature 1 equal to 0, so we use R1 of 0, 1. It has feature 2 equal to zero, so we use R_2 of 0, 1. It has feature 3 equal to 1, so we use R_3 of 1, 1. And so on. I've shown the feature values in blue to make it clear which arguments to the R functions they're responsible for. Similarly, I've shown the 1's that come from the fact that we're computing the positive score in green.

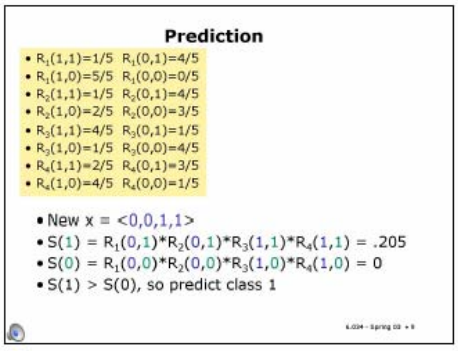
Each of the factors in the score represents the degree to which this feature tends to have this value in positive examples. Multiplied all together, they give us a measure of how likely it is that this example is positive.

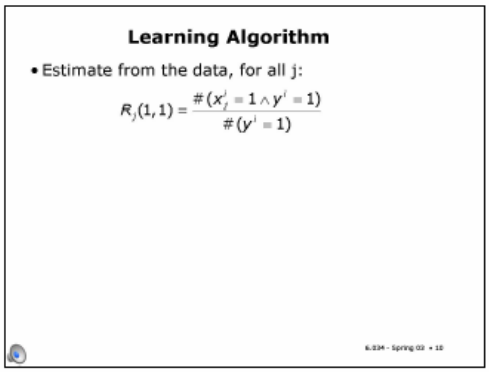




Slide 9.5.8
We can do the same thing to compute a score for x being a negative example. Something pretty radical happens here, because we have R_1 of 0, 0 equal to 0. We've never seen a negative example with feature 1 off, so we have concluded, essentially, that it's impossible for that to happen. Thus, because our x has feature 1 equal to 0, we think it's impossible for x to be a negative example.

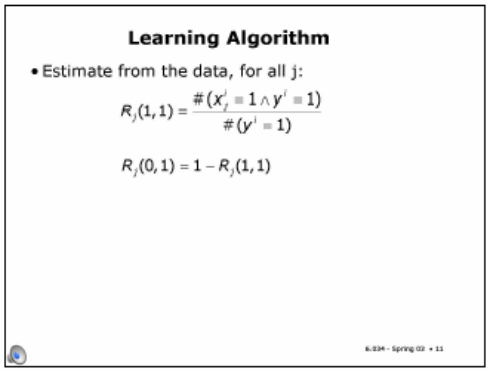
Slide 9.5.9
Finally, we compare score 1 to score 0, and generate output 1 because score 1 is larger than score 0.

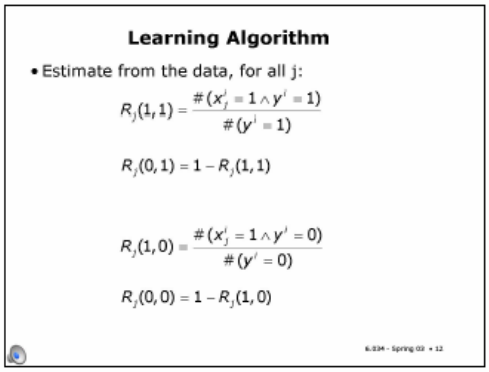




Slide 9.5.10
Here's the learning algorithm written out just a little bit more generally. To compute R_j of 1, 1, we just count, in our data set, how many examples there have been in which feature j has had value 1 and the output was also 1, and divide that by the total number of samples with output 1.

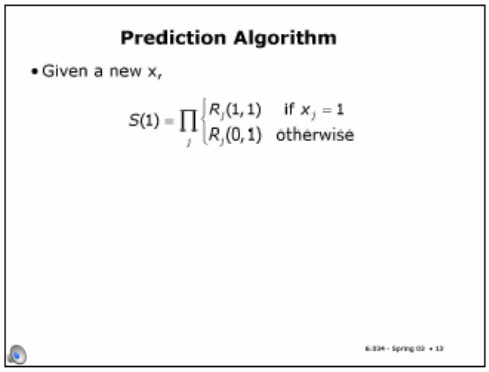
Slide 9.5.11
Now, R_j of 0, 1 is just 1 minus R_j of 1, 1.





Slide 9.5.12
Similarly, R_j of 1, 0 is the number of examples in which feature j had value 1 and the output was 0, divided the total number of examples with output 0. And R_j of 0, 0 is just 1 minus R_j of 1, 0.

Slide 9.5.13
Now, given a new example, x, let the score for class 1, S(1), be the product, over all j, of R_j of 1,1 if $x_j = 1$ and R_j of 0, 1 otherwise.



Prediction Algorithm

- Given a new x,

$$S(1) = \prod_j \begin{cases} R_j(1,1) & \text{if } x_j = 1 \\ R_j(0,1) & \text{otherwise} \end{cases}$$

$$S(0) = \prod_j \begin{cases} R_j(1,0) & \text{if } x_j = 1 \\ R_j(0,0) & \text{otherwise} \end{cases}$$

Slide 9.5.14
Similarly, S(0) is the product, over all j, of R_j of 1, 0 if $x_j = 1$ and R_j of 0,0 otherwise.

Slide 9.5.15
If S(1) is greater than S(0), then we'll predict that Y = 1, else 0.

Prediction Algorithm

- Given a new x,

$$S(1) = \prod_j \begin{cases} R_j(1,1) & \text{if } x_j = 1 \\ R_j(0,1) & \text{otherwise} \end{cases}$$

$$S(0) = \prod_j \begin{cases} R_j(1,0) & \text{if } x_j = 1 \\ R_j(0,0) & \text{otherwise} \end{cases}$$

- Output 1 if $S(1) > S(0)$

Prediction Algorithm

- Given a new x,

$$\log S(1) = \sum_j \begin{cases} \log R_j(1,1) & \text{if } x_j = 1 \\ \log R_j(0,1) & \text{otherwise} \end{cases}$$

$$\log S(0) = \sum_j \begin{cases} \log R_j(1,0) & \text{if } x_j = 1 \\ \log R_j(0,0) & \text{otherwise} \end{cases}$$

- Output 1 if $\log S(1) > \log S(0)$

Better to add logs than to multiply small probabilities

Slide 9.5.16
We can run into problems of numerical precision in our calculations if we multiply lots of probabilities together, because the numbers will rapidly get very small. One standard way to deal with this is to take logs everywhere. Now, we'll output 1 if the log of the score for 1 is greater than the log of score 0. And the log of a product is the sum of the logs of the factors.

Slide 9.5.17
In our example, we saw that if we had never seen a feature take value 1 in a positive example, our estimate for how likely that would be to happen in the future was 0. That seems pretty radical, especially when we only have had a few examples to learn from. There's a standard hack to fix this problem, called the "Laplace correction". When counting up events, we add a 1 to the numerator and a 2 to the denominator.

If we've never seen any positive instances, for example, our R (1,1) values would be 1/2, which seems sort of reasonable in the absence of any information. And if we see lots and lots of examples, this 1 and 2 will be washed out, and we'll converge to the same estimate that we would have gotten without the correction.

There's a beautiful probabilistic justification for what looks like an obvious hack. But, sadly, it's beyond the scope of this class.

Laplace Correction

- Avoid getting 0 or 1 as an answer:

$$R_j(1,1) = \frac{\#(x_j^i = 1 \wedge y^i = 1) + \mathbf{1}}{\#(y^i = 1) + \mathbf{2}}$$

$$R_j(0,1) = 1 - R_j(1,1)$$

$$R_j(1,0) = \frac{\#(x_j^i = 1 \wedge y^i = 0) + \mathbf{1}}{\#(y^i = 0) + \mathbf{2}}$$

$$R_j(0,0) = 1 - R_j(1,0)$$

Example with Correction

f_1	f_2	f_3	f_4	y
0	1	1	0	1
0	0	1	1	1
1	0	1	0	1
0	0	1	1	1
0	0	0	0	1
1	0	0	1	0
1	1	0	1	0
1	0	0	0	0
1	1	0	1	0
1	0	1	1	0

- $R_1(1,1)=2/7$ $R_1(0,1)=5/7$
- $R_1(1,0)=6/7$ **$R_1(0,0)=1/7$**
- $R_2(1,1)=2/7$ $R_2(0,1)=5/7$
- $R_2(1,0)=3/7$ $R_2(0,0)=4/7$
- $R_3(1,1)=5/7$ $R_3(0,1)=2/7$
- $R_3(1,0)=2/7$ $R_3(0,0)=5/7$
- $R_4(1,1)=3/7$ $R_4(0,1)=4/7$
- $R_4(1,0)=5/7$ $R_4(0,0)=2/7$

6.034 - Spring 03 • 18

Slide 9.5.18
Here's what happens to our original example if we use the Laplace correction. Notably, R_1 of 0, 0 is now 1/7 instead of 0, which is less dramatic.

Slide 9.5.19
And so, when it comes time to make a prediction, the score for answer 0 is no longer 0. We think it's possible, but unlikely, that this example is negative. So we still predict class 1.

Prediction with Correction

- $R_1(1,1)=2/7$ $R_1(0,1)=5/7$
- $R_1(1,0)=6/7$ $R_1(0,0)=1/7$
- $R_2(1,1)=2/7$ $R_2(0,1)=5/7$
- $R_2(1,0)=3/7$ $R_2(0,0)=4/7$
- $R_3(1,1)=5/7$ $R_3(0,1)=2/7$
- $R_3(1,0)=2/7$ $R_3(0,0)=5/7$
- $R_4(1,1)=3/7$ $R_4(0,1)=4/7$
- $R_4(1,0)=5/7$ $R_4(0,0)=2/7$

- New x = <0,0,1,1>
- $S(1) = R_1(0,1)*R_2(0,1)*R_3(1,1)*R_4(1,1) = .156$
- $S(0) = R_1(0,0)*R_2(0,0)*R_3(1,0)*R_4(1,0) = .017$
- S(1) > S(0), so predict class 1

6.034 - Spring 03 • 19

Hypothesis Space

- Output 1 if

$$\prod_j \alpha_j x_j + (1-\alpha_j)(1-x_j) > \prod_j \beta_j x_j + (1-\beta_j)(1-x_j)$$

- Depends on parameters $\alpha_1 \ldots \alpha_n, \beta_1 \ldots \beta_n$ (which we set to be the R_j values)

6.034 - Spring 03 • 20

Slide 9.5.20
What's the story of this algorithm in terms of hypothesis space? We've fixed the spaces of hypotheses to have the form shown here. This is a very restricted form. But it is still a big (infinite, in fact) hypothesis space, because we have to pick the actual values of the coefficients a_j and b_j for all j.

Slide 9.5.21
All of our bias is in the form of the hypothesis. We've restricted it significantly, so we would now like to choose the as and bs in such a way as to minimize the error on the training set. For somewhat subtle technical reasons (ask me and I'll tell you), our choice of the R scores for the alphas and betas doesn't exactly minimize error on the training set. But it usually works pretty well.

The main reason we like this algorithm is that it's easy to train. One pass through the data and we can compute all the parameters. It's especially useful in things like text categorization, where there are huge numbers of attributes and we can't possibly look at them many times.

Hypothesis Space

- Output 1 if

$$\prod_j \alpha_j x_j + (1-\alpha_j)(1-x_j) > \prod_j \beta_j x_j + (1-\beta_j)(1-x_j)$$

- Depends on parameters $\alpha_1 \ldots \alpha_n, \beta_1 \ldots \beta_n$ (which we set to be the R_j values)
- Our method of computing parameters doesn't minimize training set error, but it's fast!

6.034 - Spring 03 • 21

Appendix B: List of Sites Used for Training Data

URL	rating
http://www.tamu.edu/anthropology/news.html	0
http://www.calacademy.org/research/anthropology/utensil/index.html	0
http://www.nationalgeographic.com/outpost/	0
http://www.pacmuseum.qc.ca/quebec1690/jeu/english/index.htm	0
http://www.abc.se/~pa/uwa/whatis.htm	0
http://highhopes.com/21centurycalendar.html	0
http://physics.nist.gov/GenInt/Time/time.html	0
http://www.xs4all.nl/~voorburg/aztec/	0
http://webexhibits.org/calendars/	0
http://www2.worldbook.com/features/features.asp?feature=calendars&page=html/calendars.htm&direct=no	0
http://www.timechange.com/3m/	0
http://www.michielb.nl/maya/	0
http://www.kidlink.org/KIDPROJ/MCC/	0
http://aa.usno.navy.mil/faq/	0
http://www.geographia.com/	0
http://www.un.org/Pubs/CyberSchoolBus/infonation/e_infonation.htm	0
http://www.nationmaster.com/	0
http://www.aneki.com/	0
http://www.atlapedia.com/	0
http://www.odci.gov/cia/publications/factbook/	0
http://lcweb2.loc.gov/frd/cs/cshome.html	0
http://cwr.utoronto.ca/cultural/	0
http://www.henry.k12.ga.us/pges/kid-pages/islands/default.htm	0
http://www.gergo.com/home/midi/anthems.htm	0
http://www.thenationalanthems.com/	0
http://www.pbs.org/wnet/wideangle/	0
http://www.unesco.org/whc/nwhc/pages/sites/main.htm	0
http://www.supersurf.com/	0
http://www.your-nation.com/	0
http://www.globalgang.org.uk/	0
http://www.mnh.si.edu/arctic/	0
http://www.wsu.edu:8080/~dee/MESO/ASSYRIA.HTM	0
http://www.pbs.org/wgbh/pages/frontline/shows/secret/oral/	0
http://www.nativecreative.com/kidseum/	0
http://www.cbc.ca/kids/general/time/default.html	0
http://cobblestonepub.com/pages/kidmain.htm	0
http://www.cherbearsden.com/story1.html	0
http://www.teachtsp2.com/cdonline/	0
http://cwr.utoronto.ca/cultural/	0
http://www.ipl.org/div/kidspace/cquest/	0
http://www.culturesontheedge.com/	0
http://www.afghan-network.net/Ethnic-Groups/	0
http://www.humnet.ucla.edu/humnet/folklore/peter/index.html	0
http://www.pbs.org/wgbh/pages/frontline/shows/secret/famous/	0
http://www.far-and-near.com/	0

http://www.folkart.com/~latitude/sonora/culture.htm	0
http://www.topics-mag.com/edition11/games-section.htm	0
http://www.pbs.org/kcet/globaltribe/	0
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