Automating Content Extraction of HTML Documents

Suhit Gupta
Columbia University
Dept. of Comp. Sci.
New York, NY 10027, US
001-212-939-7184
suhit@cs.columbia.edu

Gail E. Kaiser
Columbia University
Dept. of Comp. Sci.
New York, NY 10027, US
001-212-939-7000
kaiser@cs.columbia.edu

Peter Grimm
Columbia University
Dept. of Elec. Eng.
New York, NY 10027, US
001-212-939-7000
pmg23@columbia.edu

Michael F. Chiang
Columbia University
Depts. of Ophthalmology
and Biomedical Informatics
New York, NY 10032, US
001-212-305-9535
chiang@dbmi.columbia.edu

Justin Starren
Columbia University
Depts. of Biomedical
Informatics and Radiology
New York, NY 10032, US
001-212-305-3443
starren@dbmi.columbia.edu

Abstract. Web pages often contain clutter (such as unnecessary images and extraneous links) around the body of an article that distracts a user from actual content. Extraction of "useful and relevant" content from web pages has many applications, including cell phone and PDA browsing, speech rendering for the visually impaired, and text summarization. Most approaches to making content more readable involve changing font size or removing HTML and data components such as images, which takes away from a webpage's inherent look and feel. Unlike "Content Reformatting", which aims to reproduce the entire webpage in a more convenient form, our solution directly addresses "Content Extraction". We have developed a framework that employs an easily extensible set of techniques. It incorporates advantages of previous work on content extraction. Our key insight is to work with DOM trees, a W3C specified interface that allows programs to dynamically access document structure, rather than with raw HTML markup. We have implemented our approach in a publicly available Web proxy to extract content from HTML web pages. This proxy can be used both centrally, administered for groups of users, as well as by individuals for personal browsers. We have also, after receiving feedback from users about the proxy, created a revised version with improved performance and accessibility in mind.

Categories and Subject Descriptors. I.7.4 [**Document and Text Processing**]: Electronic Publishing; H.3.5 [**Information Storage and Retrieval**]: Online Information Services – *Web-based Services*

General Terms. Human Factors, Algorithms, Standardization.

Keywords. DOM trees, content extraction, reformatting, HTML documents, accessibility, speech rendering, text summarization.

1. Introduction

Web pages are often cluttered with distracting features around the body of an article that distract the user from the actual content they're interested in. These "features" may include pop-up ads, flashy banner advertisements, unnecessary images, or links scattered around the screen. Automatic extraction of useful and relevant content from web pages has many applications, ranging from enabling end users to accessing the web more easily over constrained devices like Personal Digital Assistants (PDAs) and cellular phones to providing better access to the Web for the disabled.

Most traditional approaches to removing clutter or making content more readable involve increasing font size, removing images, disabling JavaScript, etc., or a combination of these methods, all of which eliminate the webpage's inherent look-and-feel. Examples include WPAR [18], Webwiper [19] and JunkBusters [20]. All of these products involve hardcoded techniques for certain common web page designs as well as fixed "blacklists" of advertisers. This can produce inaccurate results if the software encounters a layout that it hasn't been programmed to handle. Another approach has been content reformatting which reorganizes the data so that it fits on a PDA; however, this does not eliminate clutter but merely reorganizes it. Opera [21], for example, utilizes their proprietary Small Screen Rendering technology that reformats web pages to fit inside the screen width. We propose a "Content Extraction" technique that can remove clutter without destroying webpage layout, making more of a page's content viewable at once. These techniques should also work on web pages made up of multiple content bodies, even if they are separated by the distracting features or with them interspersed within the different sections of content.

Content extraction is particularly useful for the visually impaired and blind [48]. A common practice for improving web page accessibility for the visually impaired is to increase font size and decrease screen resolution; however, this also increases the size of the clutter, reducing effectiveness. Screen readers for the blind, like Hal Screen Reader by Dolphin Computer Access [46] or Microsoft's Narrator [47], don't usually automatically remove such clutter either and often read out full raw HTML. Webaim Screen Reader [49] and IBM Homepage Reader [50] do attempt to enhance usability by pruning out duplicate pieces of information however they tend to be slow and do not give enough control to the user in directly selecting what a user may be interested in [48]. Therefore, both groups benefit from extraction, as less material must be read to obtain the desired results.

Natural Language Processing (NLP) and information retrieval (IR) algorithms can also benefit from content extraction, as they rely on the relevance of content and the reduction of "standard word error rate" to produce accurate results [13], where the error rate is number of words incorrectly processed from the original format. Content extraction allows the algorithms to process only the extracted content as input as opposed to cluttered data coming directly from the web [14]. Currently, most NLP-based algorithms require writing specialized extractors for each web domain [14][15]. While generalized content extraction is less accurate than hand-tailored extractors, they are often sufficient [22] and reduce labor involved in adopting information retrieval systems.

While many algorithms for content extraction already exist, it appears that few working implementations can be applied in a general manner. Our solution employs a series of techniques that address the aforementioned problems, and makes it easy to implement and experiment with additional algorithms.

In order to analyze a web page for content extraction, we pass web pages through an open source HTML parser, which creates a Document Object Model (DOM) tree, an approach also adopted by Chen et al. [56]. The Document Object Model (www.w3.org/DOM) is a standard for creating and manipulating in-memory representations of HTML (and XML) content. By parsing a webpage's HTML into a DOM tree, we can not only extract information from large logical units similar to Buyukkokten's "Semantic Textual Units" (STUs, see [3][4]), but can also manipulate smaller units such as specific links within the structure of the DOM tree. In addition, DOM trees are highly transformable and can be easily used to reconstruct a complete webpage. Finally, increasing support for the Document Object Model makes our solution widely portable.

One caveat is important to note: Determining the specific content that an arbitrary author intended to portray or, more significantly from our perspective, which an arbitrary user prefers to read, is very hard. Crunch extracts the "content" heuristically, with heuristics customizable by an administrator and/or by a savvy user; there is probably no precise "one size fits all" algorithm that could achieve this goal. In particular, we do not attempt to model either author or user tasks, nor their corresponding context or intentions, but any non-intrusive approach to doing so would also likely be heuristic and thus also imprecise. Therefore, one of the limitations of our framework is that Crunch may remove items from the web page that the user may be interested in, and may present content that the user is not particularly interested in. One way to ameliorate this restriction may be to summarize all removed materials in meaningful chunks, and produce this information in another pane or at the bottom of the page; another approach may be to "learn" on a per-user and/or per website basis, e.g., from data gathered via user studies like the one we report.

In section 2, we discuss the existing solutions out there. In sections 3 and 4, we describe our approach at an abstract level and addressing system implementation issues, respectively. We describe two versions of our proxy – Crunch 1 being simply the framework; and Crunch 2 with substantial improvements to the framework with respect to the plug-in API and the extensibility of the administrative interface. Section 5 presents the initial findings from our ongoing user study. We consider potential future work in section 6, finally concluding in section 7. The appendices present additional materials for interested readers.

2. Related Work

There is a large body of related work in content identification and information retrieval that attempts to solve similar problems using various other techniques. Finn et al. [1] discuss methods for content extraction from "single-article" sources, where content is presumed to be in a single body. The algorithm tokenizes a page into either words or tags; the page is then sectioned into 3 contiguous regions, placing boundaries to partition the document such that most tags are placed into outside regions and word tokens into the center region. This approach works well for single-body documents, but destroys the structure of the HTML and doesn't produce good results for multi-body documents, i.e., where content is segmented into multiple smaller pieces, common on Web logs ("blogs") like Slashdot (http://slashdot.org). In order for content of multi-body documents to be successfully extracted, the running time of the algorithm would become polynomial time with a degree equal to the number of separate bodies, i.e., extraction of a document containing 8 different bodies would run in $O(N^8)$, N being the number of tokens in the document.

McKeown et al. [8][15] similarly use semantic boundaries to detect the largest body of text on a webpage (by counting the number of words) and classify that as content. This method works well with simple pages. However, this algorithm produces noisy or inaccurate results handling multi-body documents, especially with random advertisement and image placement.

Rahman et al. [2] propose another technique that uses structural analysis, contextual analysis, and summarization. The structure of an HTML document is first analyzed and then decomposed into smaller subsections. The content of the individual sections can then be extracted and summarized. Contextual analysis is performed with proximity and HTML structure analysis in addition to "natural language processing involving contextual grammar and vector modeling" [2]. However, this proposal has yet to be implemented. Furthermore, while the paper lays out prerequisites for content extraction, it doesn't propose methods to do so.

Many approaches have been suggested for formatting web pages to fit on the small screens of cellular phones and PDAs. For instance, the Opera browser [16] uses the handheld CSS media type. Bitstream ThunderHawk [17] uses intelligent font resizing: "[It] renders the text using the Kaasila family of fonts, fine tunes images using ThunderHawk's graphic scaling, compacts the data, and sends the page to the ThunderHawk client on the wireless device" [27]. The Skweezer Proxy [28] is architected very similarly to Crunch in that it operates as a proxy and modifies the content of the webpage before sending it to the client. Sqweezer reformats web pages such that they wrap intelligently, which prevents unnecessary side scrolling, simply by reorganizing the physical layout of the webpage retaining all original content. In general, the reformatting for small screens approaches basically end up only reorganizing the content of the webpage to better fit on the constrained device but still require a user to scroll and hunt for content.

Buyukkokten et al. [3][10] define "accordion summarization" as a strategy where a page can be shrunk or expanded much like the instrument. They also discuss a method to transform a web page into a hierarchy of individual content units called Semantic Textual Units, or STUs. First, STUs are built by analyzing syntactic features of an HTML document, such as text contained within paragraph (<P>), table cell (<TD>), and frame component (<FRAME>) tags. These features are then arranged into a hierarchy based on the HTML formatting of each STU. STUs that contain HTML header tags (<H1>, <H2>, and <H3>) or bold text (<B>) are given a higher level in the hierarchy than plain text. This hierarchical structure is finally displayed on PDAs and cellular phones, but typically showing different content than the original work. In particular, once the STU has been identified, Buyukkokten, et al. [3][4] perform summarization on the STUs to produce the content that is then displayed on PDAs and cell phones. While Buyukkokten's hierarchy is similar to our DOM tree-based model, DOM trees remain highly editable because they abstract the tags away from the content, unlike the STUs, but can easily be reconstructed back into a complete webpage – although summarization filters could similarly be applied to select subtrees. Further, DOM trees are a widely-adopted W3C standard, easing support and integration of our technology.

Kaasinen et al. [5] discuss methods to divide a web page into individual units likened to cards in a deck. Like STUs, a web page is divided into a series of hierarchical "cards" that are placed into a "deck". This deck of cards is presented to the user one card at a time for easy browsing. The paper also suggests a simple conversion of HTML content to WML (Wireless Markup Language), resulting in the removal of simple information such as images and bitmaps from the web page so that scrolling is minimized for small displays. The cards are created by this HTML to WML conversion proxy [5]. While

this reduction has advantages, the method proposed in that paper shares problems with STUs. The problem with the deck-of-cards model is that it relies on splitting a page into tiny sections that can then be browsed as windows. But this means that it is up to the user to determine on which cards the actual contents are located, and since this system was used primarily on cell phones, scrolling through the different cards in the entire deck soon became tedious.

Chen et al. [56] propose a similar approach to the deck of cards method, except in their case using the DOM tree for organizing and dividing up the document. They propose showing an overview of the desired page so the user can select the portion of the page he/she is truly interested in. When selected, that portion of the page is zoomed into full view. One of their key insights is that their overview page is actually a collection of semantic blocks that the original page has been broken up into, each one color coded to show the different blocks to the user. This, very nicely, provides the user with a table of contents from which to select the desired section. While this is an excellent idea, it still involves the user clicking on the block of choice, and then going back and forth between the overview and the full view.

None of these concepts solve the problem of automatically extracting just the content, although they do provide simpler means in which the content can be found. These approaches perform limited analysis of web pages themselves and in some cases information is lost in the analysis process. By parsing a webpage into a DOM tree, we have found that one not only gets better results but has more control over the exact pieces of information that can be manipulated while extracting content.

3. Our Approach

Our solution employs multiple extensible techniques that incorporate the advantages of the previous work on content extraction like accordion summarization and content discovery, and attempts to avoid the common pitfalls like noisy results and slow performance. Since a content extraction algorithm can be applied to many different applications, for example in the fields of NLP and IR, as well as assistive technologies like those that help the visually impaired, we implemented it so that it can be easily used in this variety of cases. Through an extensive set of preferences, the extraction algorithm can be highly customized for different uses. These settings are easily editable through the GUI, through method calls that have been exposed through a simple API, or direct manipulation of the settings file on disk. The GUI itself can also easily be easily integrated (as a Swing JPanel for Crunch 1.0 or as a standard widget for Crunch 2.0) into any Java project, or one can customize it directly. The content extraction algorithm is also implemented as an interface for easy incorporation into other programs. The content extractor's broad set of features and customizability allow others to easily add their own version of the algorithm to any product. Further discussion on Crunch as a framework can be found in Section 4.2.

In order to analyze a web page for content extraction, the page is first passed through an HTML parser that corrects HTML errors and then creates a DOM tree representation of the web page. (HTML on the Internet can be extremely malformed and most popular browsers like Internet Explorer and Mozilla are able to handle incorrect HTML by making the closest guess to what the HTML should be.) Once parsed, the resulting DOM document can be seamlessly shown as a webpage to the end-user by flattening the tree and producing back the HTML.

This process accomplishes the steps of structural analysis and structural decomposition

analogous to those done by several other techniques (see Section 2). The DOM tree is hierarchically arranged and can be analyzed in sections or as a whole, providing a wide range of flexibility for our extraction algorithm. Just as the approach mentioned by Kaasinen et al. modifies the HTML to restructure the content of the page, our content extractor navigates the DOM tree recursively, using a series of different filtering techniques to remove and adjust specific nodes and leave only the content behind. In our first attempt, Crunch 1.0, we designed a one-pass system that extracted content by running a series on filters one after the other, i.e., the selected filters just ran sequentially on the output produced by the previous filters. This caused problems at times when parts of a webpage that the user wanted were removed. In Crunch 2.0, we amended this by making it a multi-pass system. Here we keep multiple copies of a webpage in memory and a filter checks for the optimal copy to work on. A large number of examples demonstrating the results of different filter settings are shown in Appendix A.

Crunch as a framework handles the webpage, but the filters that are plugged into the framework make it dynamic and customizable. The framework defines a standard API, shown in Section 4.2.3, which a programmer implements when creating a plug-in. The programmer also decides the order in which the filters are run in order to maximize the benefit of each one. An example construction of a Crunch 2.0 plug-in is given in Section 4.2.4. Each of the filters can be easily turned on and off either by the user, the administrator or the programmer, and can potentially be customized to a certain degree through a GUI if provided by the programmer.

There are two sets of filters that we have implemented, with different levels of granularity, in both Crunch 1.0 and 2.0. The first set of filters simply ignores tags or specific attributes within tags but keep track of them in memory. With these filters, images, links, scripts, styles, and many other elements can be quickly removed from the web page. This process of filtering is similar to Kaasinen's conversion of HTML to WML. However, the second set of filters is more complex and algorithmic, providing a higher level of content extraction. This set, which can be extended, currently consists of the advertisement remover, the link list remover, the removed link retainer and the empty table remover. In Crunch 2.0, we also added filters that allow the user to control the font size and word wrapping of the output, and heuristic functions guiding the multi-pass processor, to evaluate the acceptability of the output as each filter pass edits the DOM tree. This ensures that we don't suffer from some of the pitfalls of version 1.0 where occasionally pages returned null outputs after passing through Crunch, e.g., link heavy pages like www.msn.com, as shown later in Figures 11 and 12. Finally, in the newer version, we have attempted to allow for greater control on most of the filters by adding supplementary options. For example, users now have the ability of controlling, at a finer granularity, complex web pages where certain HTML structures are embedded within others, e.g., within table cells.

The advertisement remover uses a common and efficient technique to remove advertisements. As the DOM tree is parsed, the values of the "src" and "href" attributes throughout the page are surveyed to determine the servers to which the links refer. If an address matches against a list of common advertisement servers, the node of the DOM tree that contained the link is removed. This process is similar to the use of an operating systems-level "hosts" file to prevent a computer from connecting to advertiser hosts. Hanzlik [6] examines this technique and cites a list of hosts, which we use for our advertisement remover. In order to avoid the common pitfall of deploying a fixed blacklist of advertisers, our software also periodically updates the list from http://accs-net.com, a site that specializes in creating such blacklists. This is a technique employed by most ad blocking software.

The link list remover employs a filtering technique that removes all “link lists”, which are bodies of content either in the page or within table cells for which the ratio of the number of links to the number of non-linked words is greater than a specific threshold (known as the link/text removal ratio). When the DOM parser encounters a table cell, the Link List Remover tallies the number of links and non-linked words. The number of non-linked words is determined by taking the number of letters not contained in a link and dividing it by the average number of characters per word, which we preset as 5 (although it may be overridden by the user and could, in principle, be derived from the specific web page or web domain). If the ratio is greater than the user-determined link/text removal ratio (default ratio is set to 0.35), the content of the table cell (and, optionally, the cell itself) is removed. This algorithm succeeds in removing most long link lists that tend to reside along the sides of web pages while leaving the text-intensive portions of the page intact.

After these steps, we have found that numerous tables that are either completely empty or have several empty cells take up large swaths of space remain on the webpage. The empty table remover removes tables that are empty of any “substantive” information. The user determines, through settings, which HTML tags should be considered to be substance and how many characters within a table are needed to be viewed as substantive, set much like the word size or link-to-text ratio settings set earlier. This does not require much prior knowledge of HTML since the syntax of the markup language is simple and matches words from the English language closely, e.g., table, form, etc. The table remover checks a table for substance after it has been parsed through the filter. If a table has either no substance or less than some user defined threshold, it is removed from the tree. This algorithm effectively removes any tables left over from previous filters that contain small amounts of unimportant information. This filter is typically run towards the end to maximize its benefit.

While the above filters remove non-content from the page, the removed link retainer adds link information back at the end of the document to keep the page browsable. The removed link retainer keeps track of all the text links that are removed throughout the filtering process. After the DOM tree is completely parsed, the list of removed links is added to the bottom of the page. In this way, any important navigational links that were previously removed remain accessible, and since the parser had parsed them initially as separate units, each menu or navigational link is kept intact and they can all be viewed without any loss of original setup or style.

After the entire page is parsed and modified appropriately, it can be output in either HTML or as plain text (filters could be added to translate to another output format such as WML). The plain text output removes all the tags and retains only the text of the site, while eliminating most white space. The result is a text document that contains the main content of the page in a format suitable for summarization, speech rendering or storage. This technique is significantly different from Rahman et al. [2], which states that a decomposed webpage should be *analyzed* using NLP techniques to find the content. It is true that NLP techniques may produce better results, but at the cost of far more time consuming processing. Our algorithm doesn’t technically find the content but instead eliminates likely non-content. In this manner, we can still process and return results for sites that don’t have an explicit “main body”.

Crunch, however, does have some limitations:

1) Crunch cannot filter non-HTML content like Flash. It allows a boolean choice of whether to keep or remove such structures but it can't help edit or filter within the animation itself.

2) Dynamically generated pages often aren't filtered so nicely for the same reason as above. The script, whether it be javascript, ASP or JSP is either left completely disabled, causing dynamic pages to not load correctly, or left on which leaves all respective scripts active on the page.

3) Crunch does not distinguish between different users. There is only one set of options, whether an individual is using the proxy or whether it is set up as groupware.

4) There are no artificially intelligent heuristics or machine learning algorithms implemented yet, e.g., to learn a user's browsing patterns and change user (or group) settings dynamically.

4. Implementation

4.1 CRUNCH 1.0

4.1.1. *Overview*

In order to make our extractor easy to use, we implemented it as a web proxy (program and instructions are accessible at http://www.psl.cs.columbia.edu/proxy). The proxy can be used as a personal filter by individual users as well as a central system for groups of people. In the case where Crunch is set up as groupware, users can access the proxy by simply setting their browser to do so, as most modern browsers can now point to external proxies for filtering content. This allows an administrator to set up the extractor and provide content extraction services for a group. The proxy is coupled with a graphical user interface (GUI) to customize its behavior. The separate screens of the GUI are shown below. **Error! Reference source not found.** shows the very broad options that can be turned off or on that ignore certain tags completely. **Error! Reference source not found.** has more advanced options that give more granular control, whereas **Error! Reference source not found.** shows controls on output. The current implementation of the proxy is in Java for cross-platform support, and has been successfully tested on Windows, MacOS, Linux and Solaris.

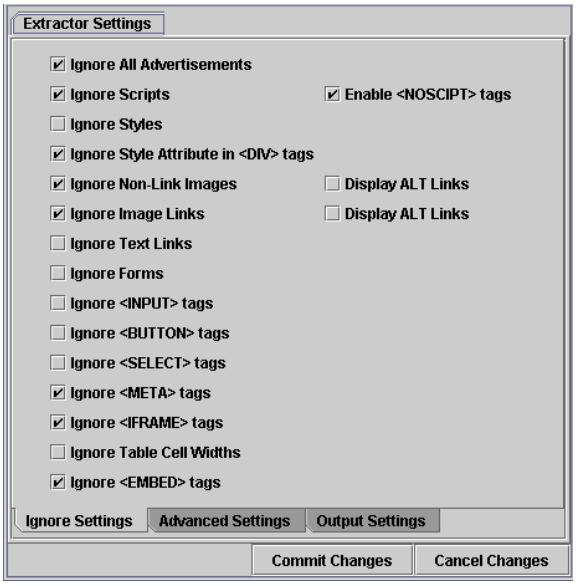


Figure 1

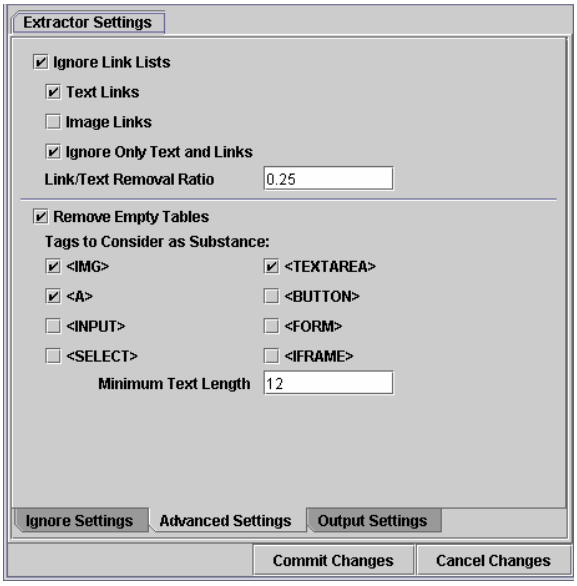


Figure 2

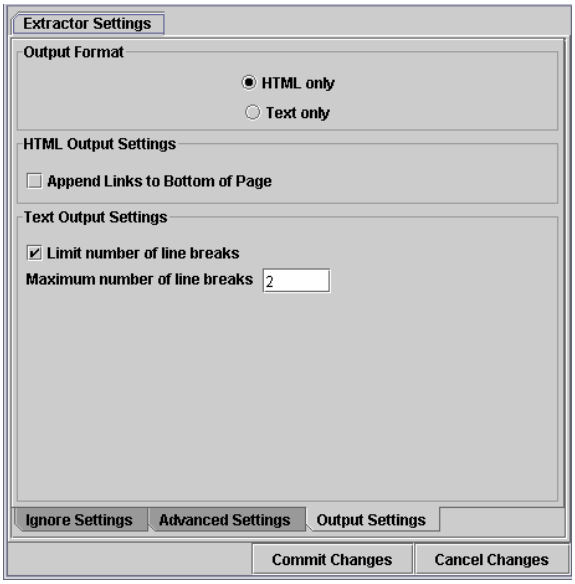


Figure 3

The Content Extraction framework itself has a complexity of O(N + P), where N is the number of nodes in the DOM tree after the HTML page is parsed and P is the sum of the complexities of the plug-ins; therefore the overall complexity is O(N) without plug-ins. Crunch 1.0 is implemented as a one-pass system, so it is the plug-ins that truly determine the running time of the system. For example, the plug-in that edits tables has an algorithm whose worst case running time is $O(M^2)$ for complex nested tables; without such nesting, the typical running time is O(M), where M is the number of elements composing the table; so the overall running time of the system works out to be $O(N + M^2)$ with the table plug-in. During tests, the algorithm performs quickly and efficiently following proxy customization. The proxy can handle most web pages, including those with badly formatted HTML, because of the

corrections automatically applied while the page is parsed into a DOM tree. However, sites that are extremely link heavy produce bad results; when the link to text ratio approaches 100%, we experienced anomalous behavior.

Figure 4 - Before

Figure 5 - After

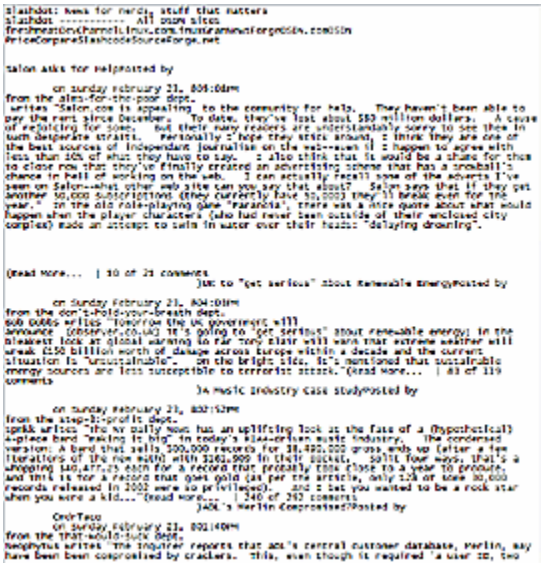


Figure 6 – Text Only

Depending on the type and complexity of the web page, the content extraction suite can produce a wide variety of output. The algorithm performs well on pages with large blocks of text such as news articles and mid-size to long informational passages. Most navigational bars and extraneous elements of web pages such as advertisements and side panels are removed or reduced in size. Figure 4 and Figure 5 show an example before and after Crunch is applied, resp. When printed out in text format, most of the resulting text is directly related to the content of the page, making it possible to use summarization and

keyword extraction algorithms efficiently and accurately. Text-only output for this example is shown in Figure 6.

The initial implementation of the proxy was designed for simplicity in order to test and design content extraction algorithms. It spawns a new thread to handle each new connection, limiting its scalability. Most of the performance drop from using the proxy originates from the proxy's need to download the entire page before sending it to the client.

4.1.2. *More examples*

Figure 7 and Figure 8 show the front page of a website dedicated to a first-person shooter game, before and after content extraction, resp. Despite producing results that are rich in text, in this particular Crunch configuration the screenshots of the game are also removed, which the user might deem relevant content. This might be a case where the user might want to tweak the default settings.

Figure 7 - Before

Figure 8 - After

Figure 9 and Figure 10 show a "link-heavy" page in its pre- and post-filtered state, resp. Since the site is a portal which contains links and little else, the proxy does not find any coherent content to keep. We investigated heuristics that would leave such pages either untouched, or alternatively employ only the most basic filters that only remove advertisements and banners, and implemented such techniques in Crunch 2.0.

Figure 9 - Before

Figure 10 - After

From these examples one may get the impression that input fields are affected irregularly by our proxy; this is because the run-time decision of leaving them in or removing them from the page is dependent on the tables or frames they are contained in. Forms are handled as one semantic unit, where either a form is displayed or not based on the user setting. Additionally, we should mention that there isn't any sort of preservation of objects that may be lost after the HTML is passed through our parser, except links can be retained as explained above. The user would have to change the settings of the proxy and reload the page to see the previously removed content. However, a different set of filters could be developed to move rather than just remove content, for forms or other identifiable HTML elements or data.

4.1.3. *Implementation details*

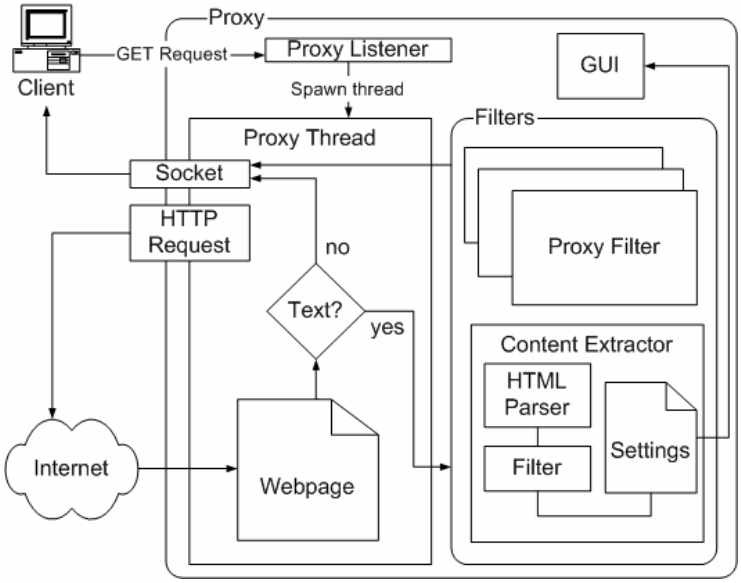


Figure 11

The life cycle of the process that gets a page to the client's browser through the proxy from a very high level is - the client passes a request for the webpage to the proxy which opens a socket, fetches the original content of the page, and parses the page to create a DOM tree representation. It is then passed through the different filters based on the settings set by the user. The edited DOM tree is then either flattened into the HTML form, to be sent back to the client's browser, or stripped of all HTML tags and only the text content is sent to the client for rendering. An architectural diagram of Crunch 1.0 is shown in Figure 11.

In more detail, in order to analyze a web page for content extraction, the page is passed through an HTML parser that creates a Document Object Model tree. The algorithm begins by starting at the root node of the DOM tree (the <HTML> tag), and proceeds by parsing through its children using a recursive depth first search function called *filterNode()*. The function initializes a Boolean variable (*mCheckChildren*) to true to allow *filterNode()* to check the children. The currently selected node is then passed through a filter method called *passThroughFilters()* that analyzes and modifies the node based on a series of user-selected preferences. At any time within *passThroughFilters()*, the *mCheckChildren* variable can be set to false, which allows the individual filter to prevent specific subtrees from being filtered. That is, certain filters can elect to produce the final result at a given node and not allow any other filters to edit the content after that. After the node is filtered accordingly, *filterNode()* is recursively called using the children if the *mCheckChildren* variable is still true.

The filtering method, *passThroughFilters()*, performs the majority of the content extraction. It begins by examining the node it is passed to see if it is a "text node" (data) or an "element node" (HTML tag). Element nodes are examined and modified in a series of passes. First, any filters that edit an element node but do not delete it are applied. For example, the user can enable a preference that will remove all table cell widths, and it would be applied in the first phase because it modifies the attributes of table cell nodes without deleting them.

The second phase in examining element nodes is to apply all filters that delete nodes from the DOM tree. Most of these filters prevent the *filterNode()* method from recursively checking the children by setting *mCheckChildren* to false. A few of the filters in this subset set *mCheckChildren* to true so as to continue with a modified version of the original *filterNode()* method. For example, the empty table remover filter sets *mCheckChildren* to false so that it can itself recursively search through the <TABLE> tag using a bottom-up depth first search while *filterNode()* uses a top-down depth first search. Finally, if the node is a text node, text filters are applied, if any.

We have implemented several basic filters in order to demonstrate the capabilities of Crunch. The pseudo-code for the text size modifier filter looks like:

```
procedure wrapTextNodes(n: node)
    if n is a textnode then
        f := new font node
        f.sizeAttribute := settings.size
        n.parent.replaceChild(n, f)
        f.addChild(n)
    else
        if n.name = "TITLE" then return
            nodes := n.getChildren()
```

```
        foreach node m in nodes
        wrapTextNodes(m)
```

And the empty table removing plug-in looks like:

```
procedure removeEmptyTables(iNode: node)
if iNode.hasChildNodes() then
    next := iNode.getFirstChild()
        while next != Ø
        begin
            current := next
            next := current.getNextSibling()
            filterNode(current)
        end

lengthForTableRemover := 0;
empty := processEmptyTable(iNode)

if empty then
    iNode.getParentNode().removeChild(iNode)
```

Please refer to section 4.2.3 to get a better look at a more in-depth description of the plug-in API.

4.2 CRUNCH 2.0

4.2.1. Overview

Crunch 1.0 nicely demonstrated the proof-of-concept design of the system as a framework, but certain problems needed to be addressed in order for Crunch to be widely used. After releasing Crunch 1.0 in September 2002, we received several suggestions from early users for additions and improvements. An informal user study of blindfolded students was conducted in May 2003 followed by a formal user study with blind and visually impaired users begun in December 2003; the first results from the latter are discussed in Section 5. The NLP group at Columbia University tried using Crunch briefly for their Newsblaster [8][9] project, which is a system that automatically tracks, clusters and summarizes each day's news programmatically. They used Crunch as their input mechanism in order to run their natural language processing algorithms on content extracted by Crunch rather than noisy data streams coming straight from the web.

As indicated in section 3, Crunch 2.0 is similar to its predecessor. However, we spent time on improving its performance and user interface, and several changes were made in the supplied set of heuristic filters, e.g., to show more useful results for link-heavy pages. We optimized the content extractor filter even though function is inherently the same. Additional filters were added that allow the user to control the font size and word wrapping of the output. Perhaps most importantly, heuristic functions were added in the form of a multi-pass system that evaluates the output the DOM tree passed through each filter. This prevents link-heavy pages like www.msn.com from returning blank pages as output; with the new result-checking heuristics of Crunch 2.0, we instead got the better results. Figure

12 shows the original form of a link-heavy page; Figure 13 and Figure 14 show the outputs from Crunch 1.0 and Crunch 2.0, respectively.

Figure 12 - Link-Heavy Page

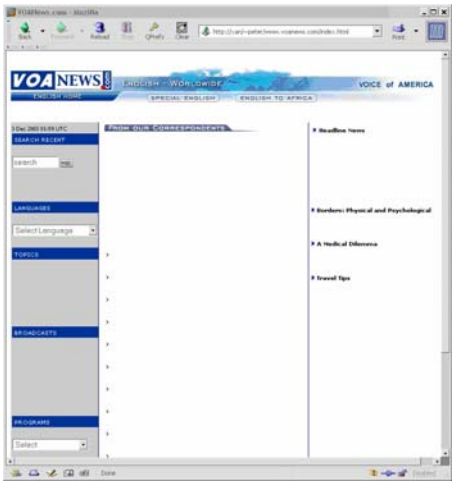


Figure 13 - Crunch 1.0 Output

Figure 14 - Crunch 2.0 Output

Finally, in the newer version, we have attempted to allow for greater flexibility to most of the filters by adding supplementary options to each. For example, users now have the ability of controlling, at a finer granularity, complex web pages where certain HTML structures are embedded within others, such as having the ability to control not only the content on the entire page but also within table cells. Appendix A show several suites of screenshots with different sets of Crunch 2.0 filters applied.

Like Crunch 1.0, the complexity of the newer version remains at O(N+P); however, the worst case running time increases to O(N*P), where N is the number of nodes in the DOM tree after the HTML page is parsed and P is the complexity of the plug-ins with highest running time. The increase in worst case complexity is due to the fact that we have switched to a multi-pass system. Therefore, in case of a bad result, a filtered webpage may have to revert to a previous state and re-run through the proxy with a different set of options; this may happen for any number of nodes in the DOM tree.

4.2.2. Technical improvements in version 2

Even though the basic architecture of the system is the same as shown in Figure 13, there are some notable changes.

1) Replaced OpenXML with NekoHTML

The original version of Crunch used OpenXML [21] as the HTML parser. OpenXML had problems with efficiency, which didn't seem likely to be fixed since OpenXML is apparently no longer an active project. So we switched to NekoHTML [23]. NekoHTML is an HTML scanner and tag balancer that parses HTML for Xerces, an XML implementation that is part of the Apache project [51]. It has many benefits, most notably the increased speed, but a key longer-term benefit is that we are now using a parser that is under active development. NekoHTML currently has some problems parsing some

pages, most notably the output not always rendering the same as the input, e.g., for certain complex nested tables and some CSS pages. However, most of these errors are minor cosmetic ones that Crunch attempts, usually successfully, to fix in its new multi-pass scheme. Additionally, the developers of NekoHTML are apparently working on its deficiencies. NekoHTML, however, does assist in our handling of multiple versions of HTML. Crunch downloads the appropriate HTML stream and sends it to NekoHTML and gets back a DOM tree upon which it applies filters. It then uses an HTML serializer to send data to the client. With this architecture, the bottleneck is NekoHTML in terms of which versions of HTML we can handle and since it can handle all versions of HTML as well as XHTML, Crunch can handle the same.

2) Performance tuning

Some speed improvement was achieved through switching to NekoHTML. The other major contributor to increased speed was the optimization of Crunch's networking code. The code was originally written using the Java IO package. Switching to the Java NIO package was considered and we wrote a small testbed, but ran into excessive complications using NIO's asynchronous callbacks. Therefore, we instead optimized the Java IO code, e.g., by collapsing multiple writes and reads, dealing with timeouts more efficiently, and removing unnecessary or redundant calls in the transfer loops. Server performance and bandwidth utilization now seems adequate, but we have not yet conducted a performance study with large loads.

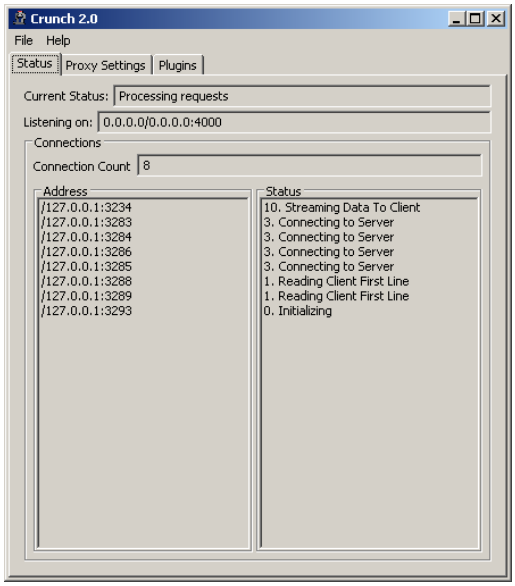
We moved to the staged event architecture and asynchronous callbacks to avoid threading scalability issues. The concept of the staged event architecture was introduced formally by Welsh [55] for performance gains in highly concurrent server applications, so that they are able to "support massive concurrency demands" [55]. We took the same concept and extended it in our framework so that Crunch can meet the demands of several parallel requests in a groupware setup.

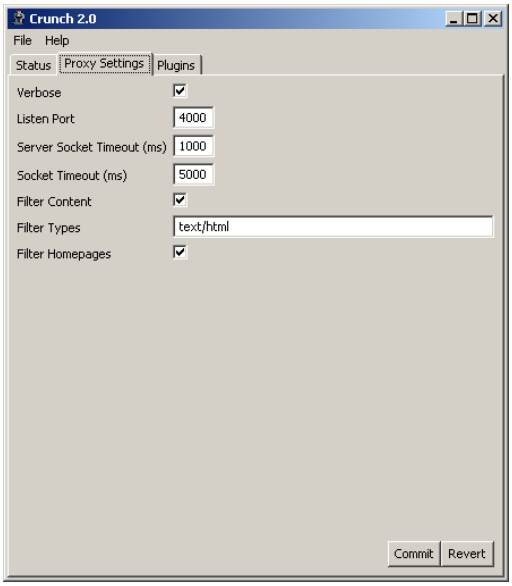
3) Switch to SWT

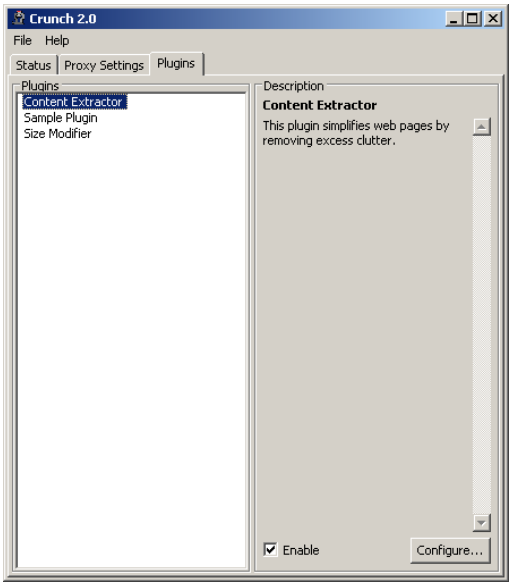
The original proxy GUI written using Java Swing was replaced using SWT, IBM's Standard Widget Toolkit [24]. SWT is highly responsive, partially due to its use of JNI and native routine calls that can take advantage of the operating system's built-in optimizations. It also uses native GUI widgets to provide a look and feel consistent with that of the operating system, while remaining operating system independent. As an added benefit, SWT allows the program to be compiled into a binary executable, resulting in a faster startup time, a smaller distribution, less memory used, and an easier installation for novice users.

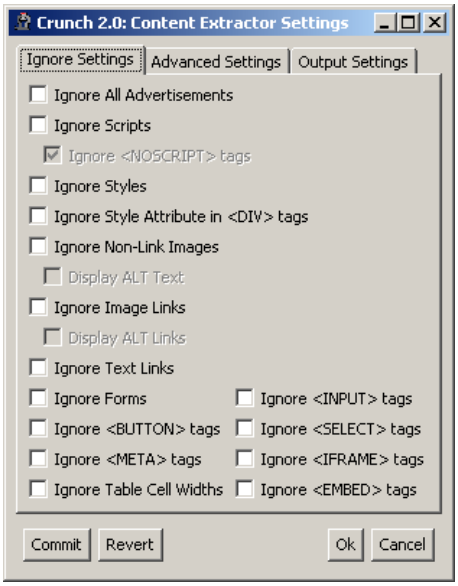
Screenshots of the new proxy GUI are shown in Table 1, where we see the basic settings and the available plug-ins in the first row and the actual plug-in setting controls in the second row. The tabs shown in the second row are similar to the original Crunch 1.0 GUI, shown in Figures 1-3; the additional tabs in the first row are new with Crunch 2.0.

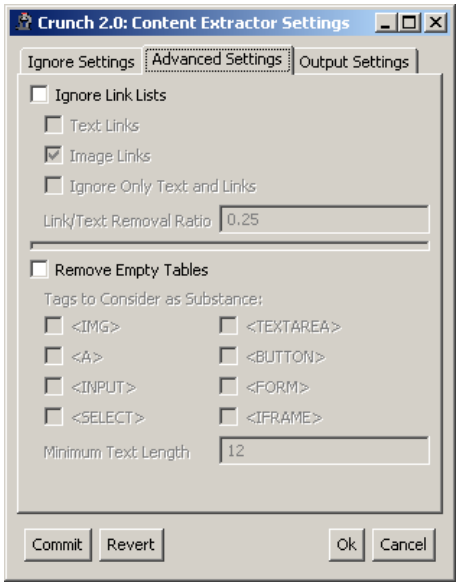
Table 1

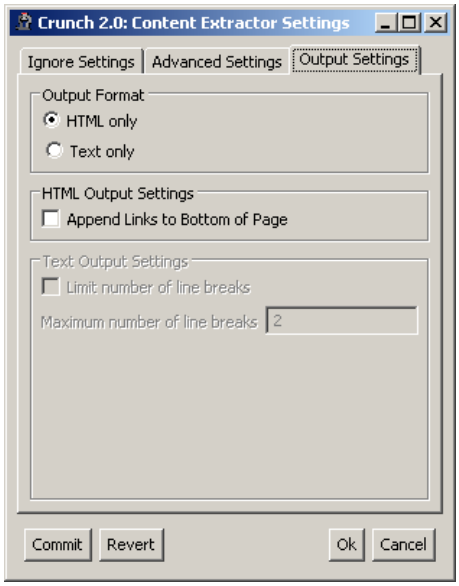












4) Accessibility

Of the plethora of benefits to switching to SWT, the most important for our purposes is accessibility. One of Crunch's main goals is to assist disabled persons in browsing the web, yet the previous version of Crunch itself, i.e., the proxy and its administrative user interface, were highly inaccessible.

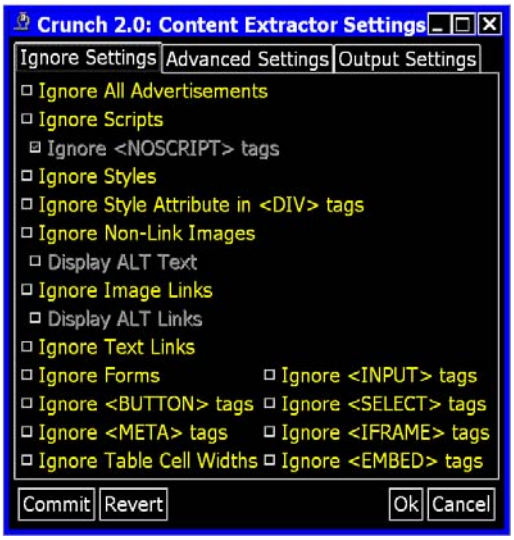
There are three basic categories of accessibility support: mobility enablement, visual enhancement, and screen readers [25]. Mobility enablement is provided in that all settings can be easily accessed through the keyboard without any assistance through the mouse. SWT provides keyboard accelerators in the API, as well as intelligently supporting tabbing through GUI components. SWT uses

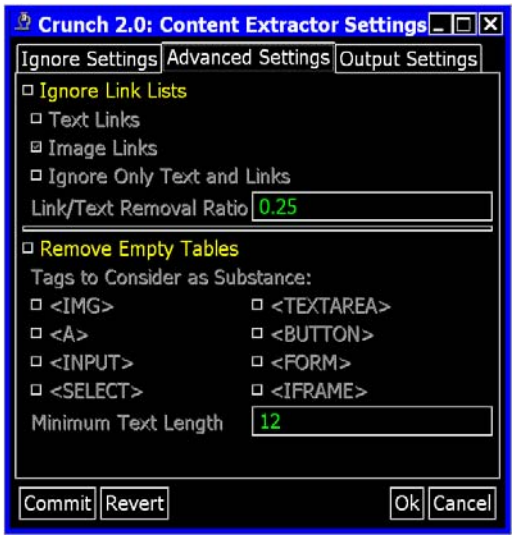
the operating system's theme for its look and feel, which means that the operating system is allowed to handle usability and visual enhancements. The best example of this is Window's accessibility features [25], such as large fonts and high contrast themes, being incorporated into the GUI. SWT also supports Microsoft Active Accessibility Support (MAAS) [26], so by default there is support for screen readers that read content from the window with focus and its associated widgets.

Usually a person requiring a screen reader will not be able to position a mouse pointer finely enough to successfully use a mouse [25], so it is important that mobility enhancement features coincide nicely with screen readers. Since SWT uses native APIs, screen readers and other accessibility options are able to work nicely together to provide the disabled with a viable way of configuring Crunch 2. As an added benefit to Windows users, SWT can use Windows themes in the same way that it uses accessibility features of the operating system [25].

Example screenshots of the proxy GUI in the high contrast scheme are shown in Table 2; compare to the second row of Table 1 (and also to Figures 1-3 from Crunch 1.0). Figure 15 shows how the user can adjust the font size of the website text from within the proxy.

Table 2





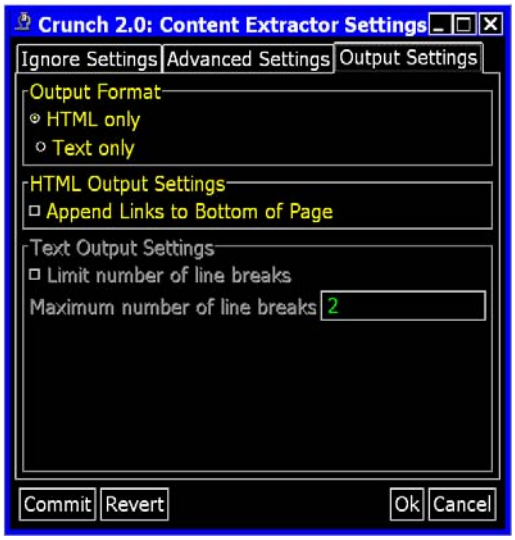


Figure 15

4.2.3. Code differences between Crunch 1.0 and 2.0

Plug-in API Improvements

The original Crunch plug-in was required to implement the ProxyFilter interface. This interface consists of 3 methods. The first and most important method is the process method. It takes a file and returns a file. It does all the processing on html content that passes through the proxy. The second method is getSettingsGUI. It returns the settings GUI so that the settings for the plug-in can be changed. The third method is getContentType. It returns the content type of the output of the plug-in.

The newer ProxyFilter was created as an abstract class. The new version is similar to the old one, but forces the plug-ins to works on the DOM documents rather than just plain files. It includes seven methods. One method is for filtering and the other methods are for GUI integration. To have the plug-in do processing on content, there is the process method. The process method takes 3 DOM documents for input. One is the document that should be processed and the other two are for reference. CurrentDocument is the document that should be processed. PreviousDocument is the output of the previous filter and is initially just a copy of currentDocument. PreviousDocument is used for rolling back changes or other analysis after changes to currentDocument have already been made. OriginalDocument represents the document as Crunch 2 has received it from the server. This allows for more advanced heuristics, quality checking, and even rollback of the processing. The methods hasSettingsGUI and getSettingsGUI are for determining if the plug-in has a settings dialog, and if it does, displaying it. Currently there is a button that can be clicked if the plug-in has a settings GUI that will display it. The methods isEnabled and setEnabled are for changing and checking the state of the plug-in. If the plug-in is disabled, it is skipped during processing of content and is shown grayed in the plug-ins tab of the main Crunch 2 window. The next two methods, getDescription and getName are used for displaying information about the plug-in and just return strings. Code details of ProxyFilter.java and ProxyFilterSettings.java are shown in **Error! Reference source not found.**.

Table 3 - Crunch 1.0 vs. Crunch 2.0 Plug-in APIs

ProxyFilter.java

```
package psl.memento.pervasive.crunch;
import java.io.*;
public interface ProxyFilter {
        public File process(File in) throws IOException;
        public ProxyFilterSettings getSettingsGUI();
        public String getContentType();
}
```

```
package psl.memento.pervasive.crunch2.plugins;
import org.w3c.dom.Document;
public abstract class ProxyFilter {
        private boolean enabled = true;

        public void getSettingsGUI() {
                // no settings GUI is required
        }

        public boolean hasSettingsGUI() {
                return false;
        }

        public abstract String getName();
        public abstract String getDescription();

        public void setEnabled(boolean b) {
                enabled = b;
        }

        public boolean isEnabled() {
                return enabled;
        }

        public abstract Document process(
                Document originalDocument,
                Document previousDocument,
```

	Document currentDocument); }
ProxyFilterSettings.java	

package psl.memento.pervasive.crunch;
 	
import javax.swing.JPanel;
 	
public abstract class ProxyFilterSettings extends JPanel {
public abstract void commitSettings();
public abstract void revertSettings();
public abstract String getTabName();
}
	package psl.memento.pervasive.crunch2.plugins;
	
	public interface ProxyFilterSettings {
	public void set(String key, String value);
	public String get(String key);
	public void commitSettings();
	public void revertSettings();
	}

The original ProxyFilterSettings extends JPanel, which is inserted into the GUI. Each proxy filter had its own tab; unfortunately this forced the implementer to use Swing, which is not available in many versions of java, such as gcc-java, also known as gcj [57]. It also doesn't unify the API for easy settings modification in the software, which is important for AI algorithms. It contains three methods: commitSettings, revertSettings, and getTabName. CommitSettings and revertSettings are for committing and reverting respectively, the settings that were made in the GUI. GetTabName is for naming the tab to put the panel in. This is usually the name of the plug-in.

The new ProxyFilterSettings is not tied to a GUI at all. Its sole purpose is to programmatically allow for the editing settings. It has four functions - Get takes a string name of the setting and passes back the value as a string. Set takes a setting name and a value and sets the setting. CommitSettings and revertSettings save the settings to a file and load the settings from a file respectively.

Notice the differences between the Crunch 1.0 and 2.0 implementations. The Crunch 2.0 plug-in implementation is now more flexible than the original. It is no longer Swing dependent. In fact, it no longer forces the user to have any sort of settings GUI. In Crunch 2.0, while no settings implementation is forced, one is provided so that all the plug-ins can have a common method of changing settings. This will simplify the implementation of any filtering heuristics using AI algorithms that could produce better results, which may need to adaptively change the user settings based on the site and the user's reaction to a given page.

Methods that run filters over content

ProxyThread.filter(HttpStream http) in Crunch 1.0 - In the original Crunch, the filter method inside ProxyThread is what passes content through the plug-ins. It works by downloading the http content to a file, and then it runs each filter on the file and updates the content type each time. After that, it replaces the content file in the http stream with the filtered file.

```
	public void filter(HttpStream http)
		throws IOException {
		File workingFile = null;
		workingFile = http.downloadToFile();
		while (filters.hasNext()) {
			try {
				ProxyFilter filter =
					(ProxyFilter) (filters.next());
				System.out.println("Started filtering...");
				workingFile.deleteOnExit();
				workingFile = filter.process(workingFile);
				workingFile.deleteOnExit();
```

```
                        http.setAttribute(
                                "content-type",
                                filter.getContentType());
                        System.out.println("Done filtering.");
                } catch (Exception e) {
                        e.printStackTrace();
                }
        }
        http.replaceContentWithFile(workingFile);
        System.out.println("content replaced");
}
```

PluginFilterRunner.process(File f) in Crunch 2.0 - In Crunch 2.0, the process method inside the PluginFilterRunner class is what runs all the plug-ins on the content. It takes a file as input. First it parses that file into xml, and then it gets a copy of that file and sets it as currentDocument. Next, it enters a loop that checks each plug-in for being enabled and, if so, rotates currentDocument and previousDocument, and then runs the plug-ins process method. After the loop, it writes the most current non-null document to a file.

```
public File process(final File f) {
        // generate xml document from file
        Document originalDocument = getXML(f);
        Document previousDocument = null;
        Document currentDocument = null;

        currentDocument = copyDocument(originalDocument);

        for (int i = 0; i < plugins.length; i++) {
                ProxyFilter plugin = plugins[i];
                if (!plugin.isEnabled())
                        continue;

                if (currentDocument != null)
                        previousDocument = currentDocument;

                if (previousDocument != null)
                        currentDocument =
                                copyDocument(previousDocument);

                currentDocument =
                        plugin.process(
                                originalDocument,
                                previousDocument,
                                currentDocument);
        }

        if (currentDocument == null)
                currentDocument = previousDocument;
        if (currentDocument == null)
                currentDocument = originalDocument;

        return xMLtoFile(currentDocument);
}
```

Content Extractor Plug-in

The Content Extractor Plug-in is the main filtering plug-in for Crunch 2.0. Its implementation is very similar to how it was in the original Crunch. This is possible even though quite a few things like the parser, etc were changed since it is all compliant with the W3C standards. The main changes were optimization, bug fixing, and working it into the new interface.

When process(Document, Document, Document) is called on the content extractor plug-in, it creates a child ContentExtractor, and has that process the currentDocument. This allows the content extractor processing to be thread safe, which is important because the proxy is multithreaded. The processing begins with the filterNode(Node iNode) method being run on the document, which is the root node of the DOM tree.

Content Extraction Plug-in filterNode method

This is a typical set of recursive methods when working with DOM. Passing through every node is very simple. FilterNode(Node iNode) passes iNode through a set of filters. Then it determines whether to filter iNode's children based on the mCheckChildren variable, which the method passThroughFilters sets. The filterChildren(Node iNode) method takes a node and runs filterNode on each of its children. Running filterNode on the root of a DOM tree will result in all the nodes being filtered recursively. This process was smoothed out in Crunch 2.0.

```
	private void filterNode(final Node iNode) {
		mCheckChildren = true;

		passThroughFilters(iNode);

		if (mCheckChildren)
			filterChildren(iNode);
	}

	private void filterChildren(final Node iNode) {
		if (iNode.hasChildNodes()) {
			Node next = iNode.getFirstChild();
			while (next != null) {
				Node current = next;
				next = current.getNextSibling();
				filterNode(current);
			}
		}
	}
```

Content Extraction Plug-in: Main Filtering Method - passThroughFilters method

PassThroughFilters(Node iNode) takes a node and determines what filters in the content extractor plug-in to run on it. MCheckChildren is changed to tell the recursive method not to check a given node's children. The first thing passThroughFilters(Node iNode) does is gather information about the node. Currently it gets the node's type, parent, and attributes. Then it runs filters based on the node type. Currently the only node type that it runs filters on are element nodes. Element nodes represent tags such as
 and <FONT>. Element nodes are filtered in several stages. The first stage is more information gathering. The node is checked for being a link and then if it is an image. This information is recorded, and then the node is passed through a second set of filters. The second set of filters only modifies element attributes. Currently the attributes that are modified are the width attributes of tables and table cells, and the style attributes of div elements. After the attributes are modified, the element is passed through filters that can delete element nodes. An example of a node to delete is an ad link. This code sequence worked well in the previous version so we stayed with it.

```
	private void passThroughFilters(final Node iNode) {
		//Check to see if the node is a Text node or an element node and
		//act accordingly
		int type = iNode.getNodeType();
		Node parent = iNode.getParentNode();
```

```
		//Get the attributes of the node
		NamedNodeMap attr = iNode.getAttributes();

		//Element node
		if (type == Node.ELEMENT_NODE) {

			String name = iNode.getNodeName();
			//================================================================
			// Set of conditions that just check the nodes without editing or
			// deleting them
			//================================================================
			//Any type of link is encountered
			if (isLink(iNode))
				recordLink(iNode);
			if (isImage(iNode))
				recordImage(iNode);

			//================================================================
			// Set of conditions that edit the nodes but don't delete them
			//================================================================

			//<TD|TABLE width=*> removes widths
			if ((name.equalsIgnoreCase("TD") || name.equalsIgnoreCase("TABLE"))
				&& settings.ignoreCellWidth) {
				if (hasAttribute(iNode, "width"))
					removeAttribute(iNode, "width");
			} //if

			//<DIV style=*> removes style
			else if (
				name.equalsIgnoreCase("DIV") && settings.ignoreDivStyles) {
				if (hasAttribute(iNode, "style"))
					removeAttribute(iNode, "style");
			} //if

			//================================================================
			//Set of conditionals determining what to ignore and not to ignore
			// (Conditions that DELETE nodes from the DOM tree)
			//================================================================
			if (isAdLink(iNode) && settings.ignoreAds) {
				parent.removeChild(iNode);
				mCheckChildren = false;
			}
			//<TD> with Link/Text Ratio higher than threshold
			else if (name.equalsIgnoreCase("TD") && settings.ignoreLinkCells) {
				testRemoveCell(iNode);
			}
			//<A HREF> with no Images
			else if (isTextLink(iNode) && settings.ignoreTextLinks) {
				parent.removeChild(iNode);
				if (settings.addLinksToBottom)
					enqueueLink(iNode);
				mCheckChildren = false;
			}
			//<BODY>
			else if (name.equalsIgnoreCase("BODY"))
				mBodyNode = iNode;
		} //if (type == Node.ELEMENT_NODE)
	}
```

Example Check Methods

- *isLink(Node iNode)*: isLink checks to see if a Node is a link. First, it gets the node type and the node attributes. Then it checks to see if the node is an element and it contains an HREF attribute. If that is true, then it returns true indicating that the node is a link. Otherwise it returns false.

```
private boolean isLink(final Node iNode) {
        int type = iNode.getNodeType();

        NamedNodeMap attr = iNode.getAttributes();

        if (type == Node.ELEMENT_NODE) {
                String name = iNode.getNodeName();
                if (name.equalsIgnoreCase("A")) {
                        for (int i = 0; i < attr.getLength(); i++) {
                                if(attr.item(i).
                                  getNodeName().
                                  equalsIgnoreCase("HREF")) {
                                        return true;
                                } //if
                        } //for
                } //else if
        } //if

        return false;
}
```

- *isImage(Node iNode)*: isImage checks to see if the node is an image.

```
private boolean isImage(final Node iNode) {
        boolean image = false;

        //Check to see if the node is an image
        int type = iNode.getNodeType();
        if (type == Node.ELEMENT_NODE) {
                if (iNode.getNodeName().equalsIgnoreCase("IMG"))
                        image = true;
        } //if

        return image;
}
```

- *isImageLink(Node iNode)*: This method checks to see if a node is a link with an image as the link or if the node is an image, it checks if it is a link. First, it checks to see if the node is a link, and then it checks to see if any of its children are images. If that is true, then the method returns true, indicating the node is an image link. Second, it checks if the node is an image, and if its parent is a link. If this is the case, it will indicate that the node is an image link. Maps are also check for and treated as image links. Otherwise, it returns false.

```
private boolean isImageLink(final Node iNode) {
        boolean imageLink = false;

        //Check to see if the node is a link
        if (isLink(iNode)) {

                //Check to see if the children have an image in it
                if (iNode.hasChildNodes()) {
                        Node next = iNode.getFirstChild();

                        while (next != null && !imageLink) {
                                Node current = next;
                                next = current.getNextSibling();
                                if (isImage(current))
                                        //imageLink = true;
                                        return true;

                        } //while
                } //if
        } //if
        //If the node is an image, check if its parent is a link
```

```
            else if (isImage(iNode)) {
                    if (isLink(iNode.getParentNode()))
                            //imageLink = true;
                            return true;
                    else {
                            // check for image maps
                            if (nodeContainsAttribute(iNode, "usemap"))
                                    //imageLink = true;
                                    return true;
                    }

            } //else if

            return imageLink;
    } //isImageLink
```

Note that while it would be trivial to add content based filters, Crunch does not currently attempt to do any NLP-level "understanding" of the content, although one of its purposes, as previously stated, is to find the content so NLP algorithms can process it without also dealing with all the clutter.

4.2.4. Example plug-ins for PDAs

One very important requirement is that Crunch be able to support existing and new heuristics invented by others (that is, by persons and organizations other than the Crunch developers), following a modular approach. One popular application for content reformatting and filtering heuristics is retargeting conventional web pages to the small screens of PDAs. Most web pages are designed for resolutions upwards of 800x600 while a majority of PDAs support only 240x320. Numerous utilities and tools have been developed attempting to solve this problem, some of which were discussed in Section 2.

We believe that many of the algorithms and heuristics underlying these tools (as well as other web page filters and reformatters devised for other purposes by third parties) could easily be integrated with Crunch via the plug-in interface. New filtering and reformatting approaches oriented towards a variety of applications could also be easily prototyped by third parties using our plug-in approach, particularly the improved API developed for Crunch 2.0. See Table 3 to compare the Crunch 1.0 and 2.0 extension APIs.

For instance, we found it very easy to re-implement both the ThunderHawk PDA browser [27] and the Sqweezer proxy [28] functionalities (both discussed in more detail in Section 2) as Crunch plug-ins, giving results essentially identical to the original utilities. If the source code of either system had been available, the relevant code could have instead been integrated directly, also via a plug-in. Part of the GUI for the Thunderhawk-like plug-in was shown in Figure 15 (there in the high contrast format).

The plug-in that simulated the functionality of Thunderhawk that we implemented is on the order of about 150 lines of code. Similarly, the Skweezer plug-in was about 140 lines of code. We have found that most of our plug-ins average about 200 lines of code.

To implement any such plug-in, one would create a class that extends ProxyFilter. The method that should do the actual processing is the process(Document, Document, Document) method. It should be thread safe because multiple threads can be accessing it at the same time.

```
        public abstract Document process(
                Document originalDocument,
                Document previousDocument,
                Document currentDocument);
```

Crunch 2.0 can be told to load the plug-in at initialization by editing the constructor of Crunch2.java to have a line like

```
                proxy.registerPlugin(new SkweezerPlugin());
```

appended to the already existing plug-ins.

```
                proxy.registerPlugin(new ContentExtractor());
                proxy.registerPlugin(new SamplePlugin());
                proxy.registerPlugin(new SizeModifier());
```

The order these lines appear in is the order the plug-ins are applied to filtered content. In this manner, one can add any number of plug-ins.

5. User Study: Web accessibility by visually disabled users

5.1 INTRODUCTION: WEB ACCESSIBILITY

Crunch can be used for many purposes, ranging from reformatting for small screens, to keyword extraction for information retrieval, to preprocessing Web pages for devices and software aides for disabled users. We had a unique opportunity to participate in a brief "user study" that compared conventional screen readers for the blind and visually impaired with the same screen readers but operating on the Web page content extracted by Crunch rather than directly on the posted Web page. The study was performed using Crunch 1.0, but we anticipate the results would be similar with Crunch 2.0.

The number of visually impaired Web users (and computer users in general) is expected to increase dramatically as the population continues to age. For example, it is estimated that the number of Americans over the age of 65 will double between 2000 and 2040 [34]. In 1997, the United States Census Bureau estimated that there were 7.7 million adults with "non-severe visual limitation," which was defined as "difficulty with seeing words and letters, even with eyeglasses," and 1.8 million American adults with "severe visual limitation," which was defined as the "inability to see words and letters, even with eyeglasses" [35]. Persons with even minimal visual impairment are likely to encounter problems in everyday life. For example, people with vision worse than 20/40 cannot obtain an unrestricted driver's license in most states, and may require assistive devices such as magnifiers for reading [52].

The goal of visually assistive technology is to provide alternative, equivalent mechanisms for computer and Web accessibility. Screen readers translate text and graphical displays into auditory output, and have become a predominant assistive technology for users with severe visual disability [36]. However, the current quality of speech-based Web navigation is very limited. In particular, the large quantity of information on Web documents imposes an enormous cognitive load on visually disabled users who must rely on auditory transmission alone, compared to sighted users who are able to identify relevant information by visual scanning [37]. Content extraction from Web pages using Crunch provides

an opportunity to provide filtered documents as input to screen readers. This may allow visually disabled users to understand the essential content of Web documents more quickly and effectively.

We performed a preliminary usability evaluation of Crunch 1.0 to supplement screen reading software for Web navigation by visually disabled users. The study design was based on previously established usability testing and cognitive analysis methodologies, in which subjects are asked to "think aloud" while performing representative computer-based tasks [38-40]. This process was captured with full video and audio recordings, providing a source of data rich in physical, temporal, and social context [41-42]. In particular, this usability study was intended to compare the quantitative and qualitative aspects of speech-based Web navigation by a completely blind user, both with and without Crunch.

5.2 USABILITY STUDY METHODS

5.2.1 Subject and software

The subject was a 50 year-old woman who had been completely blind since birth. She had no light perception from either eye, and required a guide dog for mobility. She learned Braille as a child, finished a graduate school degree program, and was employed as a full-time teacher. The subject described herself as "comfortable" with computers and the Web, and used these regularly for work. She was very familiar with assistive technologies such as screen readers, and was able to type over 20 words per minute using a standard QWERTY keyboard.

A popular screen reading Web browser (IBM Homepage Reader®) was selected for this study because it was easy to install and integrate with Crunch. The study subject had used this particular screen reader in the past, and was asked to perform Web navigation until she felt comfortable using all basic commands.

5.2.2 Design of Web-based tasks

Two representative Web-based tasks were developed that satisfied three criteria: (1) Each task involved a website that was among the 50 most popular sites, based on the well-known PageRank algorithm [43-44]. This was to ensure that tasks were representative of common Web browsing procedures. (2) Each task was extensively bench-tested to ensure that it met a sufficient number of World Wide Web Consortium accessibility guidelines to be completed using speech-based navigation with a screen reader alone [45]. Many popular websites failed to satisfy this criterion. (3) Each task was extensively bench-tested to ensure that it functioned properly with Crunch 1.0, and that it could be completed by speech-based navigation using Crunch 1.0 together with screen reading software.

Table 4 describes the two tasks. Each task was further bench-tested to determine the sequence and number of steps required for completion with screen reading software, both with and without Crunch. Additional testing was performed to determine the optimal Crunch system configuration settings that would allow both tasks to be completed.

Table 4

Task (website)	Description
A (www.usatoday.com)	Identify and read top story under "Sports" section
B (www.cnn.com)	Identify and read top headline story

5.2.3 Test protocol

Approval for the study protocol was obtained by the Institutional Review Board at Columbia University Medical Center. The subject (who gave fully informed consent according to IRB requirements) was asked to perform Task A using the screen reader alone, and then to perform Task B using Crunch 1.0 and the screen reader. The idea is that the two tasks were deemed sufficiently "similar" to be reasonably comparable, whereas performing the same task twice, one with and once without Crunch, would contaminate the second trial.

During this process, the subject was instructed to "think aloud" and verbalize impressions while performing speech-based navigation. After completing the two tasks, the subject was asked to provide specific qualitative feedback about the testing procedure. A survey was used to rate various aspects of Web navigation, both with and without Crunch, on a five-point Likert scale: (a) Usefulness of technology for performing the task. (b) Ease of deciding next step in navigation using technology. (c) Ease of understanding Web document layout with technology. (d) Ease of locating desired information of Web document using technology. (e) Overall satisfaction with technology.

While performing the tasks, the study subject was videotaped and audiotaped using a portable usability engineering system [29, 41]. A video converter converted the monitor display to a video signal for capture on videotape using a digital video camera. A microphone provided audio input to the video camera, in order to record statements and questions, as well as the screen reader sounds. A cassette recorder was used to capture additional sounds. Finally, a standard 8mm video camera was used to record keystrokes while the user interacted with the system.

5.2.4 Data analysis

The contents of the video and cassette tapes were transcribed verbatim, and annotated with time-stamps. Tapes were then coded using a standard method adapted from previous studies, in order to note particular aspects of system usability [41]. User actions were described as an overall task, which was divided into goals and subgoals. Each subject action was coded either as a correct response, an error, or a correct response to an error. Errors were categorized into one of three groups: (1) Errors in understanding of the interface. This included selection of unintended links, incorrect interpretation or hearing of speech, and confusion with manipulation of GUI widgets or browser commands. (2) Errors in understanding of document layout or navigation. This included any confusion caused by incorrect mental representation of documents, such as misunderstanding of navigation bars, or becoming "lost" while navigating within or between pages. (3) Errors in understanding caused by Web design or browser malfunctions. This included failure to comply with standard Web accessibility guidelines [45].

The total time required to complete each task was measured. This was used to calculate the time required to complete each step of the task, based on results from bench-testing. The causes of Web browsing errors were determined from detailed analysis of audiotapes and videotapes. Numerical ratings of Web browsing surveys were tabulated.

5.3 RESULTS

5.3.1 Bench-testing of tasks

Each task was carefully reviewed to determine the sequence and number of steps required for completion, both without and with Crunch 1.0. Figure 16 demonstrates the results of this analysis for Task B, which required more steps without Crunch (65 steps) than with it (38 steps). Similarly, Task A required more steps without Crunch (73 steps) than with it (23 steps). This reduction of steps required for each task was because the content extraction process simplified direct access to the Web document contents, e.g., by removing advertisements and banner links.

Task B: Go to www.cnn.com. Identify and begin reading top headline story.

Using screen reader without CRUNCH 1.0:

(A) Open text box and go to website → CNN homepage opens.
(B) Pass 2 lines. Select "Skip to main content" link.
(C) Pass 9 lines. Select "Full Story" link → Full Story page opens.
(D) Pass 2 lines. Select "Skip to main content" link.
(E) Pass 52 lines. Begin reading story text.

Using screen reader with CRUNCH 1.0:

(A) Open text box and go to website → CNN homepage opens.
(B) Pass 2 lines. Select "Skip to main content" link.
(C) Pass 8 lines. Select "Full Story" link → Full Story page opens.
(D) Pass 2 lines. Select "Skip to main content" link.
(E) Pass 26 lines. Begin reading story text.

Figure 16

5.3.2 Features of navigation

Using a screen reader without Crunch, the subject did not successfully complete Task A ("Go to www.usatoday.com and read the top Sports story"). After 21 minutes and 15 seconds, she began reading an incorrect story. Based on the fact that this task should have taken 73 steps to complete successfully, the subject required an average of 17.5 seconds per step without Crunch. Transcription and subsequent analysis of tapes revealed that the subject made a total of 31 cognitive errors during the navigation process for Task A. Based on the taxonomy described above, these errors were classified into three categories: (1) 11 errors in understanding or using the speech-based interface. For example, the subject attempted to use a "search" function, but was unable to properly enter the desired term into the text box. (2) 14 errors in document layout or navigation. For example, the web page layout caused the screen reader to announce the full navigation bar on every page (Figure 17). Even when the subject had already reached the correct "Sports" page, she became disoriented by hearing the navigation link lists. As a result, she mistakenly re-selected the "Sports" link nine additional times. When the subject finally reached the top sports story, she failed to recognize it as a story, apparently because the document made no announcement before beginning to read the story title. Therefore, she continued past the top story and eventually selected an incorrect link as the story to read. (3) 6 errors caused by Web design or browser malfunctions. For example, the subject mistakenly attempted to select a link to an advertisement banner, believing that it contained relevant information.

Figure 17 - Task A

Using the screen reader with Crunch, the subject successfully completed Task B ("Go to www.cnn.com and read the top headline story"). After 2 minutes, she began reading the correct story. Based on the fact that this task should have taken 38 steps to complete successfully, the subject required an average of 3.2 seconds per step with Crunch. Transcription and subsequent analysis of tapes revealed that the subject did not make any cognitive errors during the navigation process. This was apparently because Crunch placed the main headline story very near the beginning of the filtered document, without extraneous navigation bar or other link lists (Figure 18).

Figure 18 - Task B

5.3.3 Qualitative user evaluation

After completing Tasks A and B, the subject was surveyed regarding attitudes toward various aspects of speech-based Web navigation without and with Crunch 1.0. Results are summarized in Table 5.

Table 5 - Scores are based on Likert scale (1=Strongly agree, 2=Agree, 3=Neutral, 4=Disagree, 5=Strongly Disagree).

Aspect of navigation	Score	
	Without CRUNCH	With CRUNCH
Useful to read Web pages	4	2
Easy to decide next step	3	2
Easy to understand Web layout	2	2
Easy to locate information	4	3
Overall satisfied with navigation	5	3

5.4 DISCUSSION OF USER STUDY

This pilot evaluation employed a usability engineering approach to analyze the application of Crunch for speech-based Web navigation by a completely blind subject. It was designed as a paired study, in which the subject was asked to perform tasks without and with Crunch. Bench-testing confirmed that Tasks A and B required a similar number of steps for completion, suggesting that they were of comparable complexity. By transcribing, time-stamping, and coding the video and audio recordings of user interactions with the system, it was possible to measure the speed and error rate of Web navigation, and to categorize the cause of each navigation error.

Overall, the results of this preliminary user study suggest that Crunch has potential to provide advantages over conventional speech-based browsing in terms of speed, error rate, and qualitative satisfaction. This is primarily by removing extraneous content, and thereby simplifying the process of finding the important information on the page. Bench-testing also demonstrated that Tasks A and B both required fewer steps for completion with Crunch than without it.

However, supplementation with content extraction is not clearly superior to conventional speech-based browsing. For example, by removing features such as link lists, Crunch has potential to cause new errors in understanding page layout and navigation. Similarly, Crunch inserts removed link lists at the end of the Web document, where they may be extremely difficult for users to navigate because of the lack of surrounding context. Finally, Crunch does not perform useful content extraction on all websites (e.g., see Figures 11 and 12), and it was difficult to develop a corpus of representative tasks for evaluation purposes.

This preliminary usability evaluation has two important limitations: (1) The study involved only one subject, and therefore could not include meaningful analysis for statistical significance or reproducibility among various users. (2) Because it involved only two standardized tasks, conclusions may not be generalizable to other Web-based tasks. These limitations are being addressed by ongoing usability studies that involve recruitment and testing of additional visually disabled subjects. Results of evaluation studies will provide additional data for iterative design improvements to content extraction systems such as Crunch, and provide insight into the cognitive models used by visually disabled users for speech-based Web navigation.

6. Future Directions

Crunch uses a third-party HTML parser to create DOM trees from web pages. We have switched to NekoHTML to resolve the problems with OpenXML. However, we still intend to support commercial parsers, such as Microsoft's HTML parser (which is used in Internet Explorer), in the next revision. Integration will be accomplished by porting the existing Crunch proxy to C#/.NET, which will allow for easy integration with COM components (of which the MS HTML parser is one).

We are continuing work towards improving the proxy's performance; in particular, we aim to improve both latency and scalability, especially with the advent of browsers such as Avantbrowser [53] and Mozilla [54] that support tabbed browsing, i.e., treating multiple open web pages as part of the same session.

We are also investigating supporting more sophisticated statistical, information retrieval and natural language processing approaches as additional heuristics to improve the utility and accuracy of our current system.

We are currently working on integrating CSS support into Crunch in order to better handle the layout. We believe that supporting the webpage's CSS will help maintain a website's original look and style even when element from the page have been removed.

We also feel that there need to be some preset defaults for certain genres of websites that users can select instead of perhaps painstakingly adjusting the fine granularity of controls that Crunch offers.

Currently we do not do any form of learning of a user's browsing habits. It may be possible to implement artificially intelligent heuristic algorithms, such as Bayesian learning or Markov Model creation, as a browser plug-in that reads metadata from the client about how to change the settings. Such a browser plug-in might provide an interface for the user to rate pages, that is, Crunch's rendition of pages, and could update Crunch's configuration via extra HTTP metadata. The improved Crunch 2.0 plug-in interface is instrumental in allowing these kinds of heuristics because it allows programmatic changes to settings. With the addition of trainable filtering, Crunch could adapt to a particular user's or group's preferences. Even basic control from the browser, without any AI, would enhance Crunch's usability because the user wouldn't have to switch applications to change a setting or to enable or disable filtering.

Finally, one of our main goals was to expose a simple API for programmers to extend, so that current and future natural language processing and information retrieval algorithms can easily be added to Crunch. This would allow users to truly be able to customize the content they would like to view on visited web pages. Full evaluation of the API and plug-in framework will not be possible until sufficient outside developers have worked with Crunch.

7. Conclusion

Many web pages contain excessive clutter around the bodies of one or more articles, the actual content of the page. Although much research has been done on content extraction, and there are many special-case solutions to remove advertising (particularly pop-ups) or reformat for small screens, it is still a relatively new field where few general purpose tools are available so most researchers must construct their content extractors from scratch. In this paper we describe two versions of our proxy –

Crunch 1 being simply the framework; and Crunch 2 with substantial improvements to the framework with respect to the plug-in API and the extensibility of the administrative interface. Our approach, working with the Document Object Model tree as opposed to raw HTML markup, enables us to apply in tandem an extensible collection of Content Extraction filters, and potentially other kinds of filters such as format translators and NLP summarizers. The heuristic filters that we have developed to date, though simple, are quite effective.

Crunch has been implemented as a freely-available web proxy that anyone can use to extract content from HTML documents for their own purposes. The second version of Crunch is fast and efficient, and allows for easy integration of third party filters as plug-ins. It also offers a simple, easy to use user interface for both administrators and end users. And perhaps most importantly, we have designed this system with accessibility in mind for the visually impaired, so as to facilitate the best possible web experience in conjunction with devices such as screen magnifiers and screen readers.

Appendix A – Example Screenshots

We show some examples of typical websites with different Crunch 2.0 options turned on. The point is to give the reader an idea of the degree of control a user can have over what he/she wants to see on a webpage. The pages we chose are:

1) A typical article from www.spacedaily.com

2) An article from a link and script heavy site, www.msnbc.com

3) An article from www.cnn.com

4) The entry page to the WWW2004 website, www2004.org

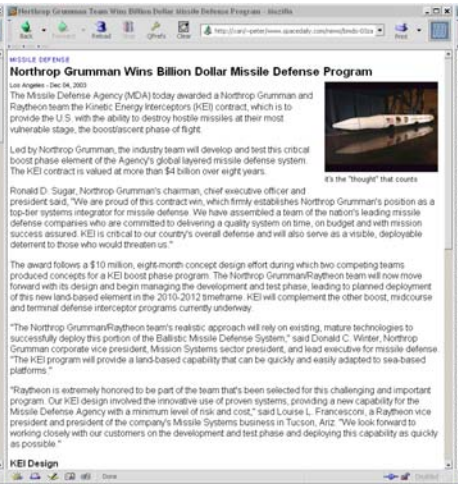
Each of the four following pages shows the corresponding set of images. The images start from a screenshot of the original site, followed by a gradual increase in the number of filters used, continuing to the screenshot that was taken of the site in text-only mode. We have created this anthology of images to help the user get an idea of how Crunch and its filters work on a given webpage.

Original

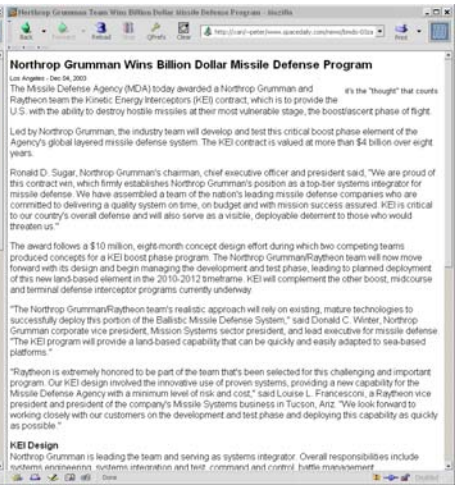
Remove link lists

Remove advertisements

All advanced filters on



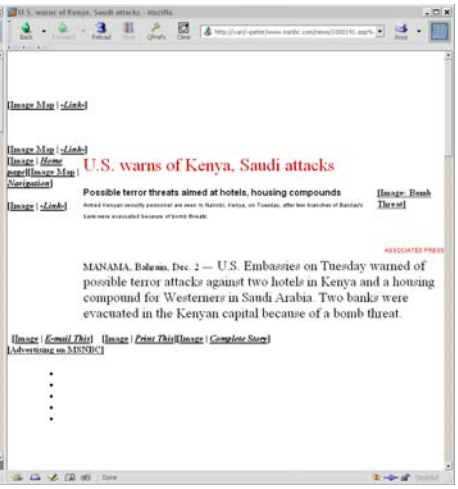
Ignore Scripts



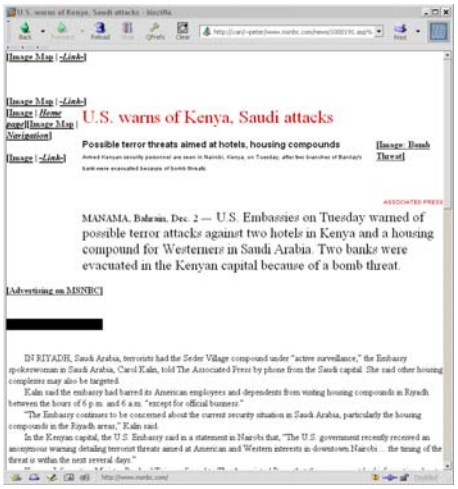
Ignore everything, text only

Original

All advanced filters on



Ignore scripts



Ignore everything, text only

Original

Remove forms

All advanced filters on

Ignore everything, text only

Original

All advanced filters turned on

Ignore everything, text only

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