VIDSEEK: Dynamic Multi-dimensional Browsing of Video Archives

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Abstract

We describe a dynamic Web-based digital video library browsing system (VIDSEEK) that allows users to preview the contents of the VISION[1] digital video library via automatically selected and organized keyframes. Our system supports dynamic clustering-on-demand, which allows users organize the digital video library clips into clusters based on multiple user-specified video features. The system also supports category-based browsing, which allows users to interactively and dynamically filter the VISION digital video library clips based on a given set of constraints, such as video source, keywords, and date of capture. We use efficient techniques to create the video abstractions, and dynamic organization, i.e., categorization or clustering, of the video abstractions to provide a sophisticated tool for video archive exploration.

1. Introduction

The vast amount of electronic information available today presents both an opportunity and a barrier to people around the world. Due to the unprecedented growth of high speed network accessibility, networks that were once primarily text-based are rapidly expanding to include graphics, animations, audio, video and interactive media. The ability to publish and access a vast array of video and multimedia information resources on a global basis has transformed many aspects of our lives.

Search engines and browsing tools are some of the most popular and widely accessed Web sites because they allow users to look for the information of interest. However, with the explosive growth of information available in the World Wide Web, most queries result in many retrieved documents, only some of which are relevant. Accessing digital video information is an even harder problem because content-based video indexing is difficult and the volume of retrieved video data is enormous. Information filtering, multi-dimensional clustering and multi-dimensional searching techniques must be developed to allow users to efficiently and effectively preview video archive contents. A well-filtered and categorized retrieval set can help users find what they are looking for in a more organized way and hence save them time. This paper reports our work in VIDSEEK system, a Web-based digital video library browsing tool, which supports user-controllable dynamic filtering and clustering of a video archive.

[1] Video Indexing for SearchIng Over Networks

2. Project Goals

The goal of this project is to develop an efficient and user-friendly Web-based video browsing system to support access to the VISION digital video library. We wish to combine the ease of use that browsing an organized collection provides with the power of searching to locate clips of interest. Thus, we are exploring ways to adapt the archive browsing structures based on user interaction. For efficiency, video clips are represented using an abstraction which include not only image features but also the closed caption, date of capture, conceptual category and video source. Through the use of these video clip abstractions, users can efficiently (in terms of access, transfer, and reviewing time) review library contents before deciding to incur the cost of accessing richer information layers or the complete video clip. Our specific aims are to provide 1) focused category-based browsing and 2) dynamic cluster based browsing of the VISION digital video library. The main features of this project are the incorporation of user interaction in the creation of the browsing structures and the use of multiple video features (image, temporal, conceptual) for video search and browsing.

2.1 Category-Based Browsing

Video clips are automatically categorized as they are added to the archive. The two level hierarchical subject tree is displayed to the user to allow category-based browsing. Users are allowed to prune the video archive on demand by specifying different combinations of features. Currently, users can focus the category contents based on video source, date of capture, and keywords but more features are being added.

2.2 Dynamic Cluster-Based Browsing

Users can choose to dynamically cluster the shots in the VISION digital video library based on a weighted combination of multiple features such as color moments, conceptual category and shape. The off-line Star algorithm [1] was used as the clustering algorithm for information organization. The clusters are presented in a rank ordered list, with the largest cluster first. By adjusting the features selected and their weights, users may create clusters which reflect their own priorities.

3. Related Work

Digital libraries store materials in electronic format and manipulate large collections of those materials effectively [21]. Digital video libraries integrate image and video processing and understanding, speech recognition, distributed data file systems, networks and human-computer interactions into a comprehensive system. Key issues are how to search, browse, and display materials effectively from and across the large collections that these libraries hold

Research at the University of San Diego [19] addresses the unique requirements of a multimedia file system, such as continuous storage and retrieval of video data from the digital video library system. Systems that incorporate image understanding and video processing include the VisualSEEk [23], WebClip [15], Princeton Deployable Video Library (PDVL) [31], the Algebraic Video System [27], and SaFe [4][24. The Informedia Digital Video Library project is establishing a large, online library featuring full content and knowledge-based search and retrieval of digital video [6][29], and it has been deployed as a News-On-Demand system [30]. The VISION system shares many goals with Informedia, but adds the constraint that all video processing must occur in real-time and work on commodity hardware [11].

3.2 <u>Video Data Searching, Browsing and Visualization</u>

Digital video libraries share many problems with generic digital libraries but the use of video information presents its own problems. A key component of this difference is the need to develop content-based indexing and retrieval algorithms to enable users to interact the video library rather than simply playing back entire movies or broadcasts. Hence, video abstraction is an essential component of digital video libraries because they enable a user to determine a video's distinguishing content without investing a long viewing time. Work using a single frame as video abstraction was done with the Informedia project from Carnegie Mellon University [25], and WebSEEk from Columbia University [24]. In these content-based searching systems, the keyframe video abstraction provides a quicker access to relevant video clips. Other project such as the Query by Image Content (QBIC) system [9][15] supports access to video collections on the basis of visual properties as the video abstraction such as color, shape and other image features. In general, these systems concentrate on accessing the video clips via image-based queries or conceptual (keyword) queries. With VIDSEEK, we are exploring the use of multiple image, temporal, and conceptual features simultaneously.

<u>3.4 Clustering and Information Retrieval</u>

Clustering is a way to impose order on data items. It is used in information retrieval to 1) organize search results [13], and 2) organize and browse library collections [13]. Current information systems such as INQUERY [26] and Smart [20] generally present search results in rank ordered lists, but it is ineffective for users to scan a list of hundreds of document titles. Hence, one of the active research areas is the exploration of retrieval set clustering and visualization techniques, which are used to provide users with a more effective overview of the contents of the retrieval set. The visualization system using the STAR algorithm on TREC data [1], the query result visualization system that allows the user to organize the search results in AMORE system was developed [16], and the Cat-a-Cone system [12] provide an interactive user interface for browsing very large category hierarchies. The use of fuzzy clustering to group similar Rframes together [2], or represent video retrieval set in a three-dimensional hierarchy [14] is just another way of representing data for a better overview of retrieval set. We will extend it to browse video collection dynamically based on user interaction

The primary goal of our VIDSEEK system is to provide a user friendly interactive interface browsing tool. We have implemented techniques for dynamic clustering and conceptual categorization creation of video data to support cluster-on-demand and category focusing flexibility. For example, a user can use closed caption and image feature based clustering to group the video clips in various ways to allow them to understand the archive content better. Or, they may select a video source and set of keywords and view the results displayed in the subject hierarchy.

4. The VISION Project Overview

The VISION digital video library system [10][11] was developed as a testbed for evaluating automatic and comprehensive mechanisms for library creation and content-based search and retrieval of video over local and wide area networks. VISION uses techniques from image and natural language processing to improve search and discovery in the video medium, partitioning video data into small clips of 'meaningful' data, and providing representative video abstraction of the library materials. Initially, users could remotely search the VISION digital video library and view selected video segments over networks of different bandwidths.

5. VISION Browsing System (VIDSEEK)

VIDSEEK (VIDeo SEEKing) allows users to browse video clips in the VISION video library over the Web. When video clips are added to the archive, they are automatically assigned a category in the two level subject hierarchy. Users may specify combinations of multiple features (video source, time of capture, keywords) to filter the contents of this hierarchy to focus it on clips of interest to them, and then browse for video clips that best meet the user's criteria. The system also supports multi-dimensional dynamic clustering based on the STAR algorithm. The user can view the abstracts of video clips clustered dynamically based on their own criteria. A Java-applet enabled frame is developed for video clip playback and streaming employing RealMedia network streaming package. The following sections discuss in detail the design and components of VIDSEEK.

5.1 VISION Browsing System (VIDSEEK) Overview

Figure 1 shows the basic block diagram of VIDSEEK Web-based browsing system architecture. The system is divided into six main components: 1) Video Processing System; 2) SQL Database Server; 3) RealMedia Server; 4) Category-Based Browsing Module; 5) Dynamic Cluster-Based Browsing Module; and 6) Web-based Video Browser. The SQL and RealMedia servers are commercial products, and thus will not be discussed further.

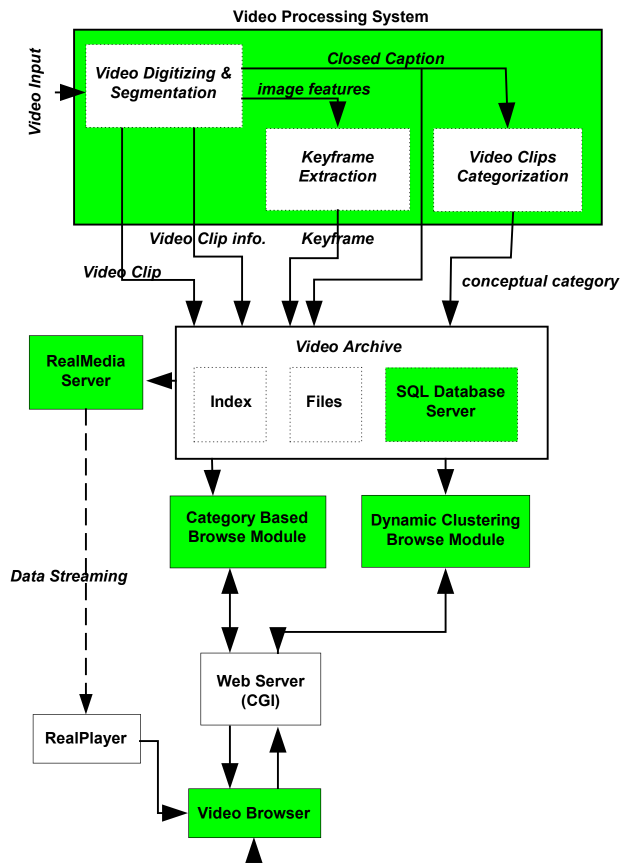

Figure 1. The System Block Diagram of VIDSEEK Browsing System.

5.2 Video Processing System

Videos, soundtracks and closed-captions are digitized and are encoded into RealMedia format for its high data compression ratio and video streaming over low bandwidth networks. The video, audio, and closed captions signals are used together to provide scene-based segmentation rather than shot-based segmentation [11]. Keyframes representing video clips are extracted by the keyframe extraction component using our stillness criteria [3]. For experimental purposes, a total length of two hours of video from four different video sources were digitized and segmented into a total of 442 video clips. We are currently building a larger archive to evaluate the scalability of our algorithms and applicability of our approach to more realistic size collection.

The video clip categorization component makes use of closed caption information of each video clip to categorize video clips into a category based on a two-level subject tree. Our categorization method is based on the vector space model and has been found more accurate than Naïve Bayes in our experiments [33]. Figure 2 gives an overview of the video clip category assignment process. Manually assigned documents and used as training data. Word matches between incoming video captions and the pre-categorized documents are used to identify the top-matching category for each clip.

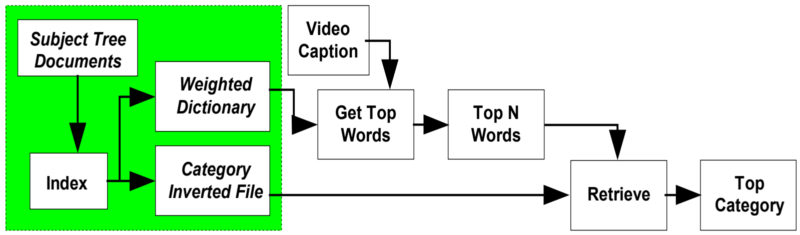

Figure 2. Conceptual category assignment process for each video clip.

5.3 Category-Based Browsing Module

5.3.1 Category-Based Browsing Engine

Users may browse the hierarchical subject tree to explore the entire archive. However, to better support browsing of large archives, users may filter the videos in the subject tree based on these features: the video source, the broadcast date, and the keywords in each video clip. The search engine retrieves the video clip abstractions which match the users' criteria, and then displays the retrieved data based on the pre-defined category of each video clip. Figure 3 shows an overview of system flow diagram of the category-based browsing engine. The system receives input queries from the Web-based interface and builds SQL queries based on the given inputs. These queries are sent to SQL Server and information retrieval engine for processing. The retrieved video abstractions are displayed in their appropriate location in the subject tree. Thus, the user is performing a hybrid of searching and browsing. They may be considered to be pruning the subject tree to make browsing easier or performing a search which produces a categorized rather than rank-ordered result set.

5.3.2 Category-Based Browsing User Interface

Figure 4 shows a screen shot of the main window of the HTML page for category-based browsing. Currently there are a total of four video sources available for browsing purposes. Options are provided for users to select different combinations of video sources, date ranges and keywords for browsing the VISION digital video library. The default setting allows users to browse the entire VISION archive.

As shown in Figure 5, the retrieved data set is presented with the video abstracts organized into a two level hierarchy. Thus, users can search and browse the database by specifying any or all of the video source, date range, and keywords that they are looking for, and the output of the retrieved data is displayed into a pre-defined category hierarchy for conceptual browsing. Users can examine further detail by clicking on a subject name, which will cause the keyframes and caption information for video clips in that category to be shown. Users can play the video clip or view all keyframes for video clips by clicking on the keyframe image and keyframe button respectively (Figure 6).

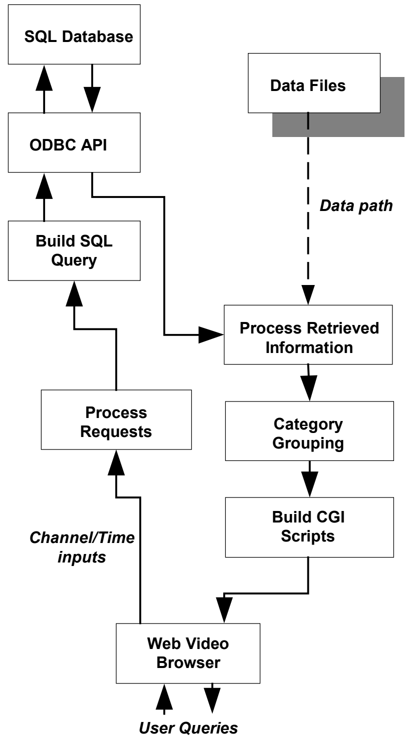

Figure 3. Overall System Flow Diagram of Category-Based Browsing Engine.

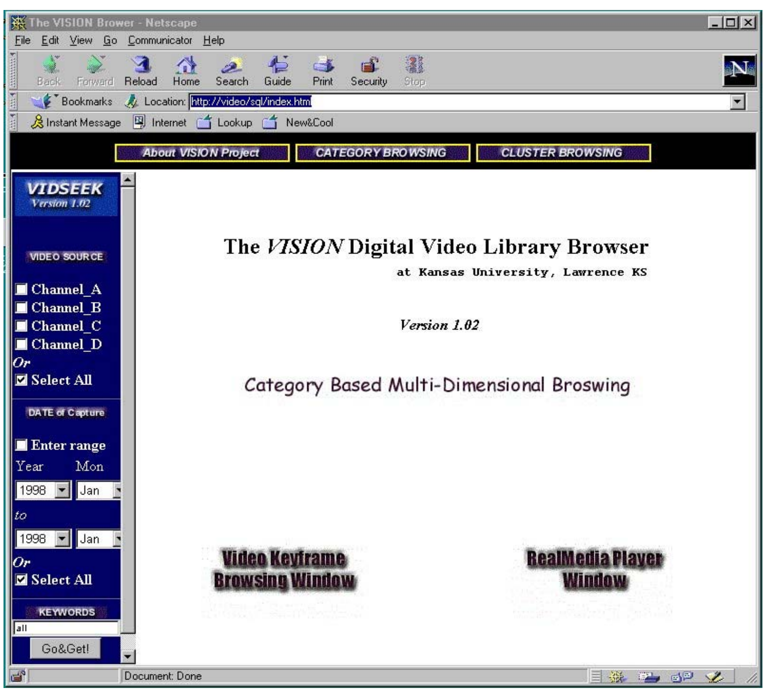

Figure 4. Screen shot of the VIDSEEK user interface for category-based browsing.

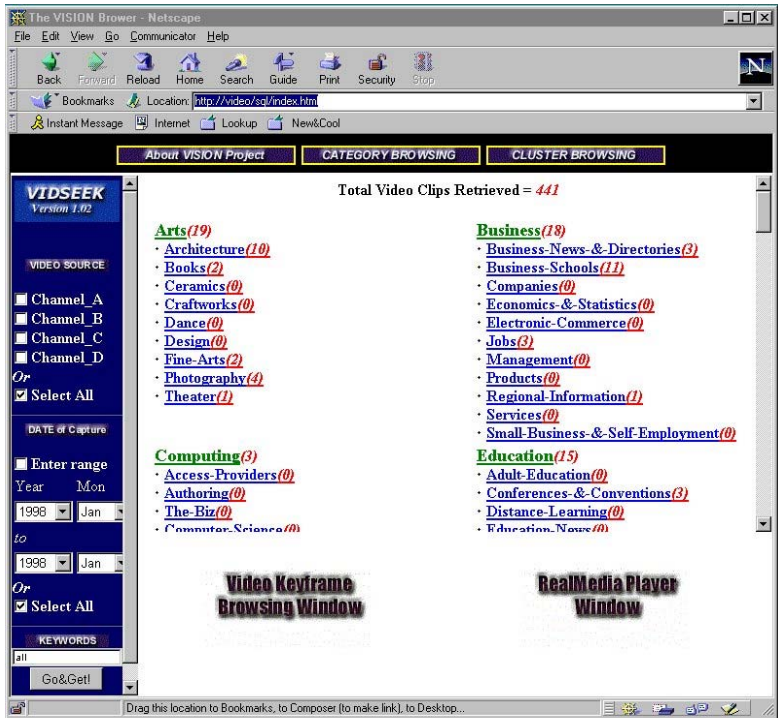

Figure 5. A screen shot of category-based multi-dimensional browsing pane.

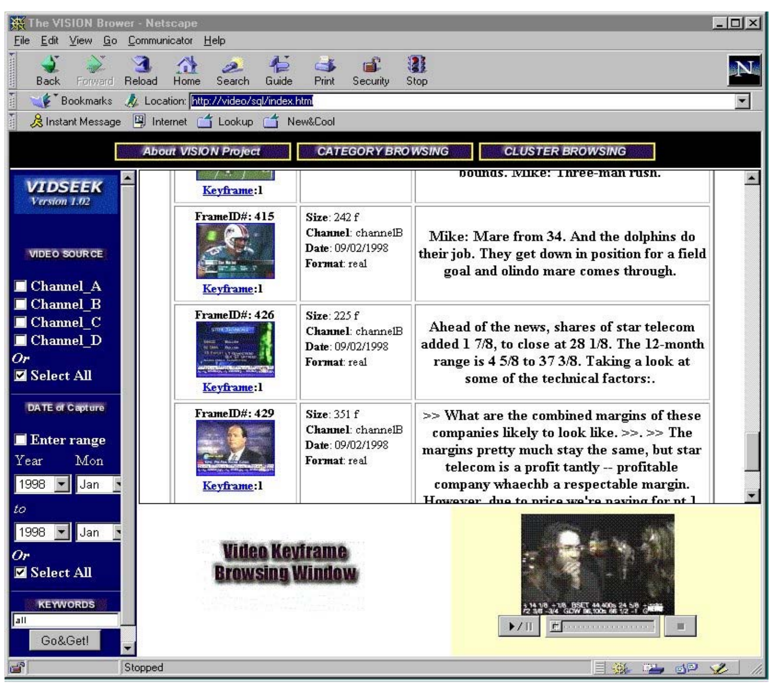

Figure 6. A screen shot of category-based multi-dimensional browsing pane.

5.4 Dynamic Cluster-Based Browsing Module

5.4.1 Dynamic Cluster-Based Browsing Engine

This clustering module allows users to interactively cluster the video clips in the VISION digital video library based on their own weighted combination of features. While any number of features may be used, the current version supports three types of features: 1) color features based on the average of 9 color moments (mean, variance and skew of each basic color) per keyframe; 2) shape features based on the average of invariant moments of keyframe; and 3) conceptual features based on match value for each of the 280 categories for each video clip. For each feature, the cosine measure is used to calculate the similarity between each pair of video clips in the archive. This information is stored in one pre-calculated N by N similarity matrix per feature (where N is the total number of the video clips in the video archive). When the clustering module receives a request from the Web-based user interface, a new similarity matrix is dynamically calculated based on the following algorithm:

$$SIM(x,y) = (W_c * S_c(x,y) + W_v * S_v(x,y) + W_s * S_s(x,y)) / (W_c + W_v + W_s)$$

where:

$SIM(x,y)$ = New Similarity Matrix
$S_i(x,y)$ = similarity between clips x and y for feature I
W_c = color moment similarity matrix weight [0….1.0] specified by users
W_v= invariant moment similarity matrix weight [0…1.0] specified by users,
W_s = category similarity matrix weight [0….1.0] specified by users

In other words, the new similarity matrix is a normalized similarity matrix resulting from the summation of the individual feature similarity matrices multiplied by the feature's weight factor. The STAR [1] clustering algorithm is used to cluster the video based on this new similarity matrix. It was chosen because it represents a 16.2% improvement in performance with respect to average link and a 21.6% improvement with respect to single link, and has a linear running time with respect to the size of the input [1]. Hence, it is highly efficient and simple to implement and it has been shown to produce high quality clusters.

The STAR algorithm proceeds as follows: A thresholded graph G_σ, which is an undirected graph, is obtained from the new similarity matrix by eliminating every edge whose weight is lower than a given threshold. The threshold σ value for creating graph G_σ calculated as follows:

H(s) = > (100 –Coverage%)∗0.01∗Total_Edges

where:

s=1..1000;
σ = s/1000;
H(s) = cumulative histogram of the new similarity matrix SIM(x,y)
Total_Edges = Total number of elements in SIM(x,y)
Coverage% = Users specified coverage percentage (1…100) which defines the percentage of the elements of the SIM(s,y) to be included in the clusters.

Hence, users choose the G_σ threshold value by specifying the percentage of the total size of new similarity matrix to be included for clustering process. Finally, a set of overlapping clusters is created from G_σ using the STAR method which is a simplified version of clique clustering [1]. Figure 7 illustrates the functionality of this on-line clustering module.

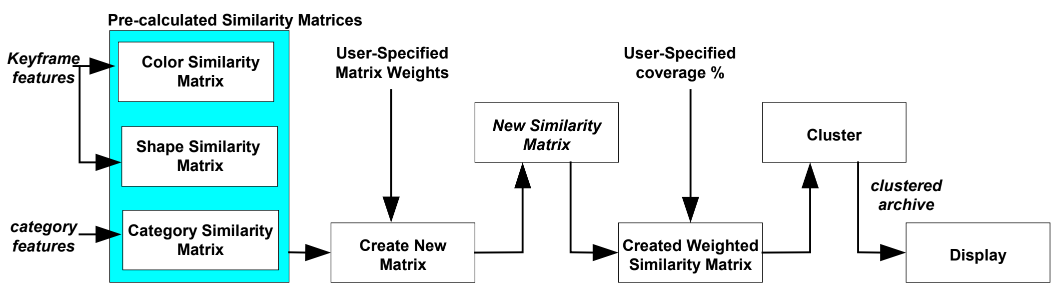

Figure 7. Functionality Flow Chart of dynamic clustering module

5.4.2 Dynamic Cluster-Based Browsing User Interface

Figure 8 shows a screen shot of the HTML page for cluster-based browsing. Users are allowed to specify a weight between 0.0 to 1.0 for each feature (color, shape, and category) which is used to determine the new video clip similarity matrix. In addition, they may specify a coverage percentage which is used to determine how many of the video clips appear in the final clusters. A high coverage percentage means that most of the clips will be shown, which may result in a large number of small clusters being formed. A low coverage percentage, in contrast, will result in only the best clusters being displayed. The created clusters are displayed in descending order by size. To give the user an indication of the cluster contents, the four most frequently found categories in each cluster are shown as well as the keyframe for the video clip which is the centroid of the cluster. As in category-based browsing, users can browse the keyframes and closed caption information for each cluster by clicking on the image icon shown at the far right of the cluster display frame and play the individual video clips.

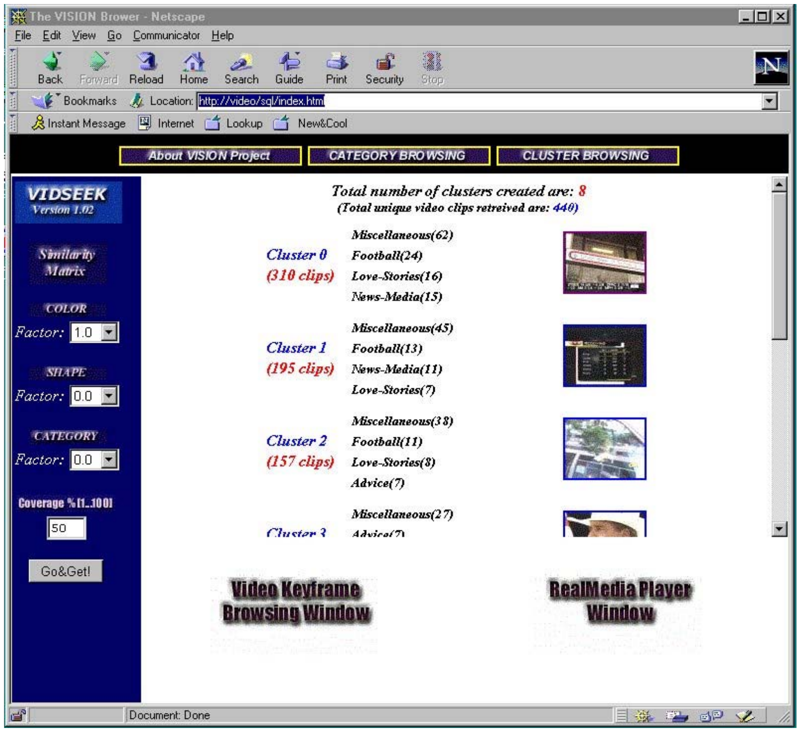

Figure 8. A screen shot of dynamic cluster-based multi-dimensional browser.

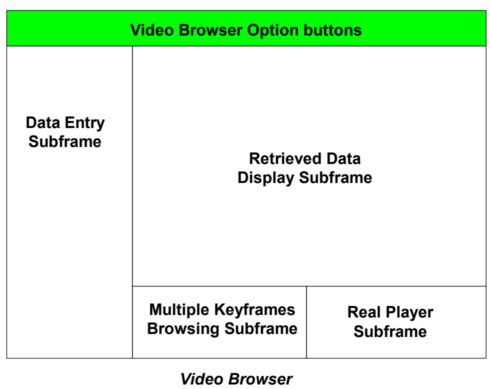

Figure 9. Basic layout of the Web-based VIDSEEK user interface.

5.5 Web-based Video Browser

The Web-based graphical user interface allows users to do category-based and dynamic cluster-based multi-dimensional browsing of the VISION digital video library. The video browser has two main windows, one for category-based multi-dimensional browsing and one for cluster-based multi-dimensional browsing. Both windows consist of four main components: 1) one pane providing entries and options for users to enter and select input requests; 2) one pane to display retrieved video abstraction information such as caption and representative keyframes; 3) one pane for browsing multiple keyframes, and 4) one pane to support a Java applet enabled RealMedia Player for video clip playback. Figure 9 shows the basic layout of the user interface.

6. Illustration

The VIDSEEK browsing system incorporates user control multi-dimensional criteria and dynamically generated browsing structures. Two retrieval scenarios are described to illustrate the usefulness of our approach.

6.1 Retrieval Scenario 1

Consider a user looking for video clips related to *Love-Stories*. He may choose to use the category-based multi-dimensional browsing tool. A request for all video sources and date ranges has returned a total of 41 video clips under the *People-Page* top category. Out of these 41 video clips, there are a number of 19 video clips being categorized under the *Love-Stories* sub-category. Hence, the user can now easily find his favorite video clips regarding *Love-Stories* by previewing the video abstraction of the *Love-Stories* sub-category. The user can also restrict the data range for the previous week and also the video source (if desired). For example, the user may choose *Channel A* as his preferred source of *Love-Stories* information. This request is sent to the category-based browsing tool and 201 total clips are retrieved, compared to 441 in the previous case, 14 of which occur in the *People-Page* top category and two in the *Love-Stories* sub-category. Hence, the user need only retrieve the video abstractions for two clips rather than 19 in the full archive. Figure 10 and Figure 11 show a screen shot of the browsing outputs of the two retrieval scenarios described above. Being able to select the video source, date range, and keywords of interest greatly reduce our browsing time and finding relevant video clip more efficiently. By presenting video abstractions such as keyframes and caption information, the user can locate the relevant video clips without having to playback all the search results which can be bandwidth and time consuming.

6.2 Retrieval Scenario 2

Consider the user looking for video clips which have *green* as the dominant color. In this browsing case, the user can use the cluster-based browsing tool to help him finding those specified video clips in the VISION digital library, if there is any. For example, the user may choose to cluster 20% of the video archive using only the color feature. This request is sent to the dynamic cluster-based browse module and 29 clusters are created, shown in descending order by cluster size. By examining the keyframes shown for each cluster, the user can determine that *cluster 9* is the predominantly *green* cluster (shown in Figure 12). However, the 30 clips in *cluster 9* cover a wide spectrum of different categories and shapes. If the user is looking for video clips related to *football* which show the arrangements of players on the field rather than close-ups of individual players, he would be interested in some of the clips in *cluster 9*. However, only 10 of the 30 clips are related to *football.*

To narrow his search more, he may choose to recluster the archive where similarity is calculated with equal weights for the color feature and the conceptual category feature (e.g., 1.0 for color feature, 1.0 for conceptual feature, and 0.0 for shape feature). When this request is sent to the cluster-based browse module, a total of 34 clusters are created.

As shown in Figure 13, the user can find video clips related to *football* with *green* color as major color component in *cluster 3*. Of the 71 predominantly *green* clips in *cluster 3*, 29 clips are related to *football*. In contrast, the next largest category in this cluster, *music*, contains only 4 clips. *Cluster 10* is predominantly red clips, and also contains 9 *football* clips out of 22 video clips in total, but these are close-ups of players in red jerseys. The result shows that the user can interactively choose to dynamically cluster a subset of the video archive based on his/her own preferred combination of multiple features, namely color, space shape, and category. In this case, the user need only examine the video abstractions in *cluster 3* for further video clip exploration. Figure 14 shows that the *football* related clips in *cluster 3* can be easily identified.

In general, as more features are used during clustering, the number of clusters created increases. This is due to the fact that a tighter and more specific constraint is applied to the clustering algorithm, and hence more clusters with fewer members are created. Therefore, video clips in the clusters are more closely related and we are able to select a cluster which contains video clips more pertinent to our information needs.

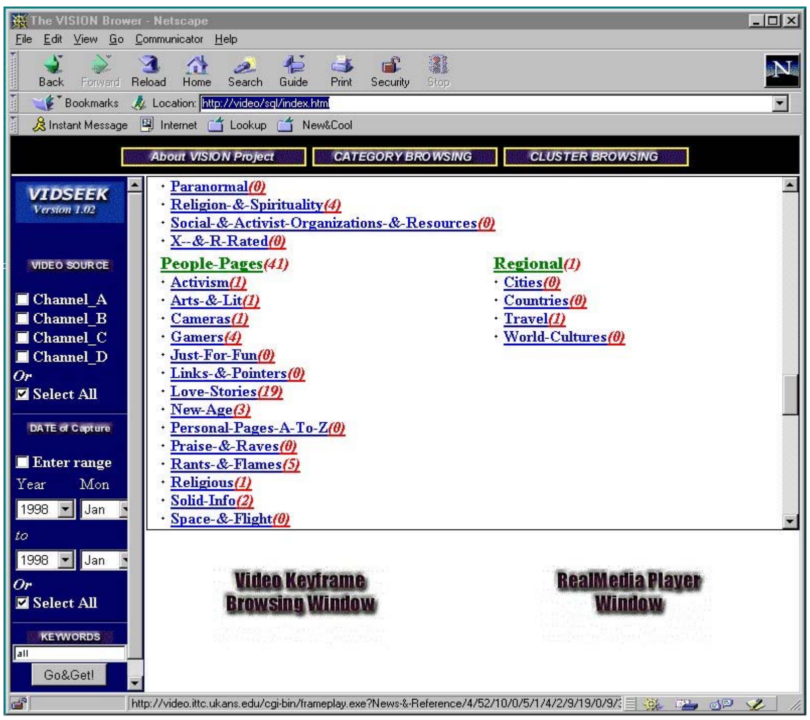

Figure 10. Category-based browse output without video source restriction.

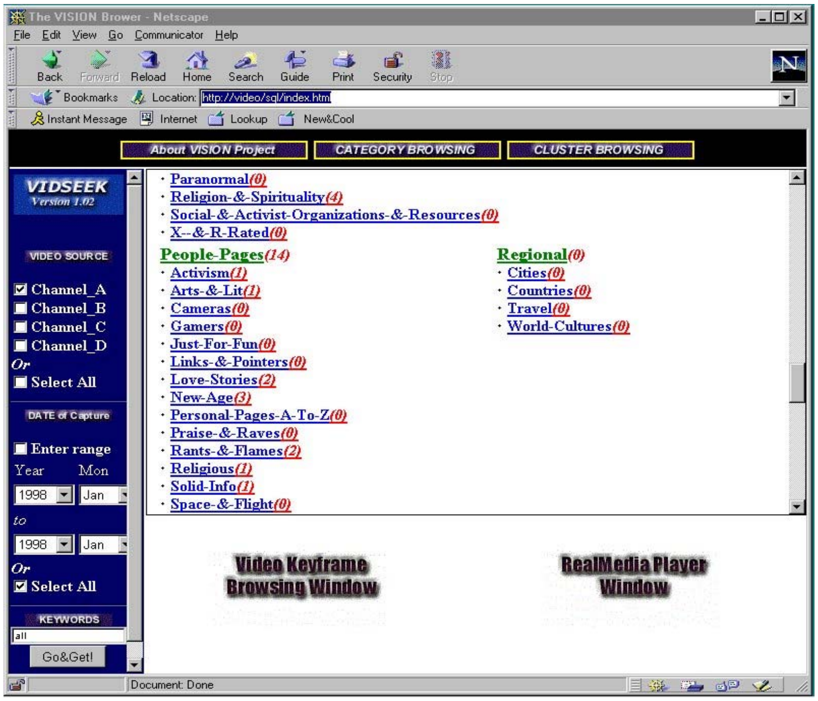

Figure 11. A screen shot of category-based browse output with video source selection.

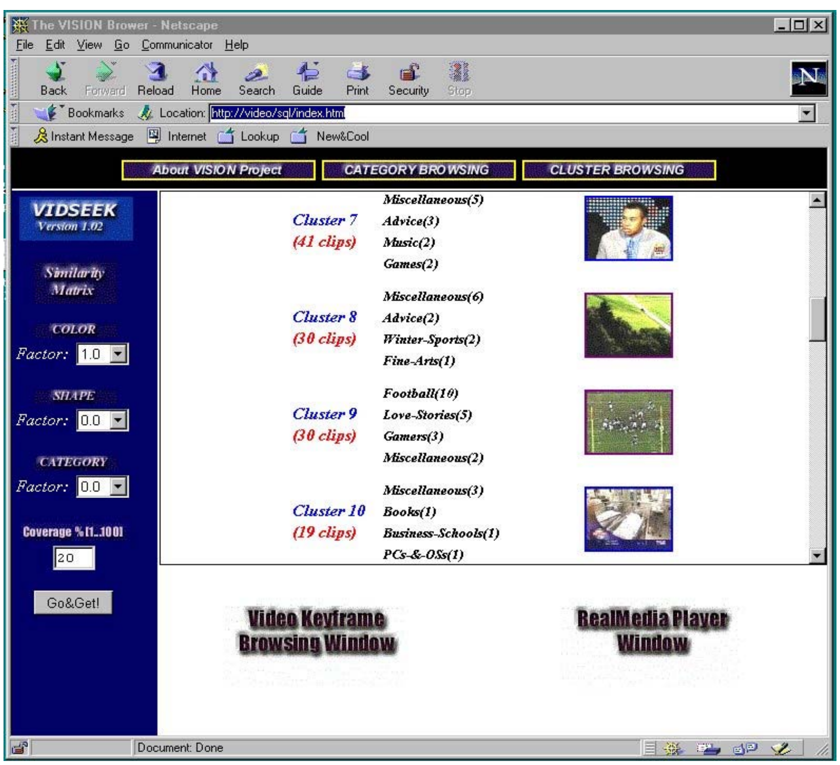

Figure 12. Screen shot of *cluster 9* generated in dynamic cluster-based browsing.

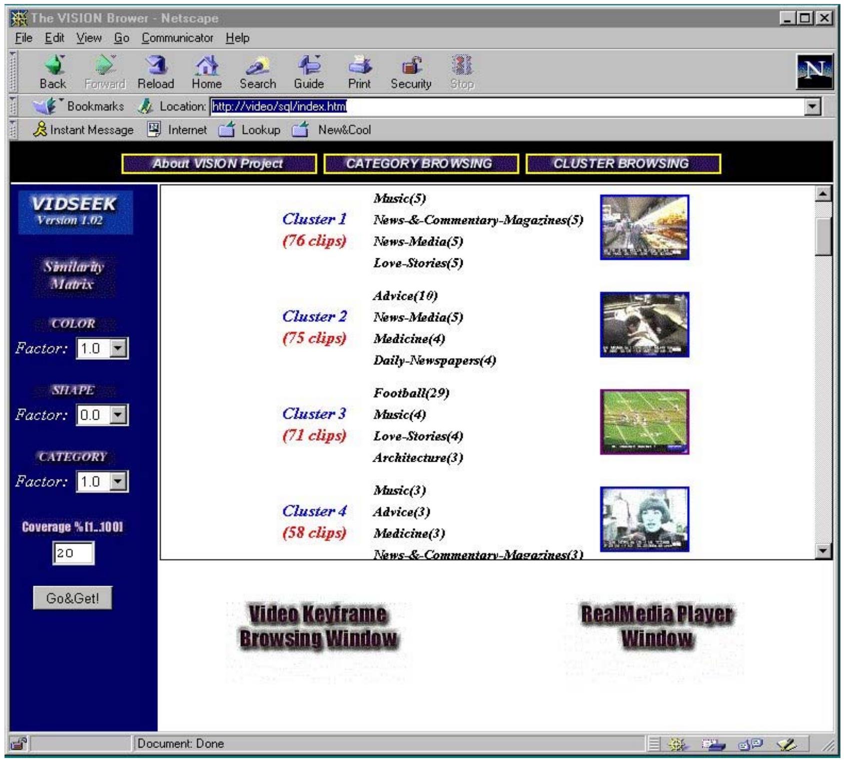

Figure 13. A screen shot of dynamic cluster-based browsing.

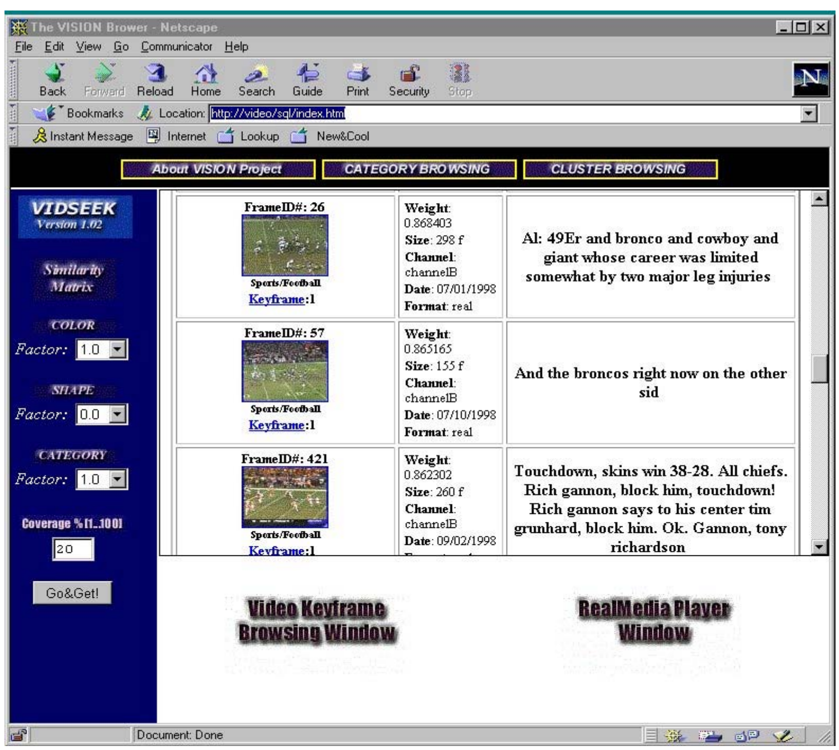

Figure 14. Screen shot of *cluster 3* generated by cluster-based browse tool.

7. Conclusion

We have motivated, described, and illustrated the performance of the VIDSEEK category-based and cluster-based multi-dimensional browsing system. VIDSEEK allows users to dynamically filter the contents of the category-based browsing structures based on multiple criteria (source, date and keywords). This provides a hybrid of browsing and searching. In addition, users can dynamically cluster the video archive based on a combination of image and conceptual features. These capabilities provide a powerful and flexible video archive exploration tool. The need for video clip playback can be reduced by allowing users to browse through video abstractions such as multiple keyframes, category and caption information which provide a summary of video clip content.

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