

Characterizing User Access To Videos On The World Wide Web

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Abstract

Despite evidence of rising popularity of video on the web (or VOW), little is known about how users access video. However, such a characterization can greatly benefit the design of multimedia systems such as web video proxies and VOW servers. Hence, this paper presents an analysis of trace data obtained from an ongoing VOW experiment in Luleå University of Technology, Sweden. This experiment is unique as video material is distributed over a high bandwidth network allowing users to make access decisions without the network being a major factor. Our analysis revealed a number of interesting discoveries regarding user VOW access. For example, accesses display high temporal locality: several requests for the same video title often occur within a short time span. Accesses also exhibited spatial locality of reference whereby a small number of machines accounted for a large number of overall requests. Another finding was a browsing pattern where users preview the initial portion of a video to find out if they are interested. If they like it, they continue watching, otherwise they halt it. This pattern suggests that caching the first several minutes of video data should prove effective. Lastly, the analysis shows that, contrary to previous studies, rankings of video titles by popularity did not fit a Zipfian distribution.

1. Introduction

Videos form a significant portion of Internet traffic. In MMCN 1998, we published an investigation of the characteristics of video data stored on the web [1]. One of our key findings was that the number of movies coming online was increasing at a rapid rate. Such an increase, coupled with the large size of the videos in our study (as opposed to other types of WWW documents), hinted that video access would soon constitute a large percentage of WWW bytes transferred on the Internet. This trend was confirmed by a recent analysis [15] of Web related traffic emanating from the entire University of Washington campus over a week in mid-January 1999. The study reported that audio/video data constituted at least 17% of all the bytes transferred.

However, despite the growing popularity of video content, little is known about how users access video on the Web. Our earlier report presents a partial picture of video usage: we know about the properties of the video files but we do not know how these files are accessed. Knowledge of access patterns is crucial for the design of systems that enhance VOW access such as video proxy caches, VOW servers, and multimedia file systems. For example, if access patterns reveal repeated requests of specific video titles by multiple clients from the same organization, client-side caching could improve access performance. Similarly, if smaller videos were more likely to be accessed than large videos, the system could be optimized accordingly. In the absence of such analyses, we conducted our own study of VOW access patterns. Our goal was to answer the following questions:

- Do accesses to videos exhibit temporal locality?
- How frequently are videos accessed compared to HTML documents?
- Do users exhibit any specific browsing patterns when viewing videos?

Our answers to these questions are based on a study of user access patterns and file characteristics of an ongoing VOW experiment in Luleå University of Technology, Sweden. This VOW experiment is unique because video material is distributed over a high bandwidth network. Hence, users can make access decisions without the network being a major factor. Similarly, the stored video data is designed for a high speed network. Sample findings from our study

included:

1. *Inter-arrival times*: median interarrival time of about 400 seconds indicate that requests for videos are nowhere near as frequent as those for HTML documents.
2. *Video browsing patterns*: users often view the initial part of videos in order to determine if they are interested or not. If they like what they see, they continue watching. Otherwise, they stop. We found that about 55% of all playbacks went to completion in our analysis. Most of the remaining 45% stopped very early on in the movie playback.
3. *Temporal Locality*: accesses to videos also exhibit strong temporal locality. If a video has been accessed recently, chances are that it will be accessed again soon.
4. *File size trends*: videos are becoming larger as more network bandwidth becomes available and low bitrate streaming protocols get deployed in video distribution. With a high bandwidth network and H.261 based multicast architecture in place, the median size of files at the Lulea University video server was 110 MBytes. Median duration was 77 minutes.

The remainder of this paper is organized as follows. Section 2 provides more information about the setup of the VOW experiment and section 3 presents an analysis of the video files actually accessed by the users during the course of the experiment. In this section, we examine the average size and duration of the video files as well as their bitrate distribution. Section 4 is divided into two parts. First, we detail our criteria for eliminating erroneous requests from the user access traces. For example, we ignore requests from the demo machine since they do not represent standard user behavior. In the second part of section 4, we report the results of our access pattern investigation on the filtered trace. We examine properties such as how user requests vary on a day to day basis and whether video accesses exhibit any temporal properties. We outline related work in section 5 and conclude with some observations in section 6.

2. Background

Since 1995, the Centre for Distance-spanning Technology at Luleå University (CDT) has been researching distance education and collaboration on the Internet [17]. Specifically, it has developed a hardware/software infrastructure for giving WWW-based courses and creating a virtual student community. The hardware aspects include the deployment of a high speed network (2-34 Mbps backbone links) to attach the local communities to the actual University campus. The campus is also connected to the national academic backbone by a high speed 34 Mbps link [13] with student apartments being wired together with the rest of campus via 10 or 100 Mbps ethernet. On the software side, the mStar environment, developed at CDT, provides a collection of web-based authoring, presentation and recording tools that use the Mbone for content delivery [8]. In particular, the mMOD (the multicast Media On Demand) system, a component of mStar, allows for recording and playback of classroom lectures, seminars and meetings [12].

The mMOD system consists of two separate programs, the VCR and the Web Controller. The VCR allows for recording and playing back of broadcasts. H.261 [14] is used for video compression in most cases. Recorded data is stored on the mMOD web server. The VCR also permits the fast forwarding or rewinding of a video stream.

The Web Controller provides an interface for the mMOD system - it allows users to request new video/audio playback sessions from the mMOD server. Additionally, it also permits users to join sessions already in progress. Users are able to view material via standard tools such as vic or vat [10]. A set of Java applets are also available for this purpose [18]. The entire system is available in a commercial version from [19].

Figure 1 shows the playback architecture of the mMOD system on the Luleå University campus. User requests arrive at the mMOD server from three main subdomains within the campus, as well as from external sources. Since the mMOD server is the focus of both recording and playback, its log files form the basis for video access analysis, while its file system records provide the raw data for determining intrinsic file characteristics.

3. Video File Characteristics

As of 10th March, 1998, the mMOD server (mmod.cdt.luth.se) hosted 139 audio/video titles that, according to the log traces, had been accessed at least once. Video content ranged from classroom lectures and seminars to traditional movies. Student enrollment in the undergraduate courses ranged from 100-140 with smaller numbers attending the

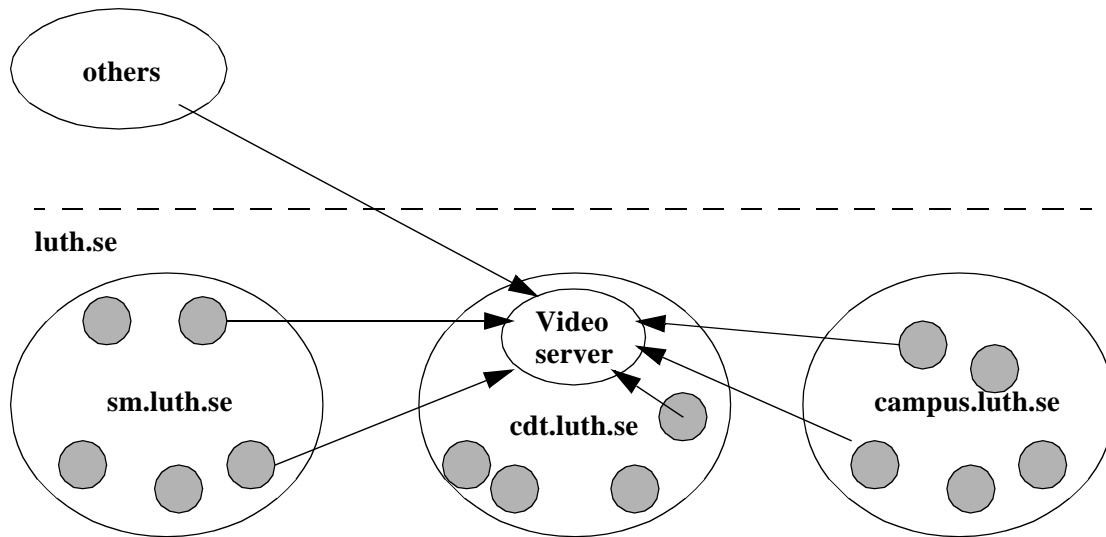


Figure 1: Video access structure on the mMOD system

graduate courses. All movies were CIF (320 x 240) in size. In the remainder of this section, we outline the basic characteristics of these file - their size, durations, and bitrate distributions.

3.1 Size

The file size analysis was based on detailed directory listings from the mMOD video server. Overall, the files totalled 15.7 Gbytes in size. Individually, each title is composed of separate audio and video files but in this analysis we aggregate them together. Figure 2 shows the individual size distribution of titles. 125 Mbytes is the most common file size and the mean value is about 121 Mbytes. In general, file sizes were several orders of magnitude larger than videos on the web.

3.2 Duration

Since no separate record exists about the duration of the titles, we determined the length of each by hand. This involved fast forwarding each title to its end via the mMOD VCR and noting the time elapsed. Some of the titles did not have accurate embedded timestamps and we ignored those for this analysis. Figure 3 displays the duration distributions of all the remaining titles. The distributions varied widely - from 10 minutes to over two hours. 90-100 minutes proved to be the most popular time range, most probably because this was the average length of a class lecture. The mean duration was approximately 75 minutes. Once again, the duration of these movies were much larger than those reported by the study of videos on the web.

3.3 Bitrate Distribution

To obtain the mean bitrate for each movie, we divided the size by its duration. Figure 4 plots the resulting bitrate distribution. The majority of the files exhibited bitrates between 150-250 kBits/sec, much lower than expected. This was because the video quality of each transmission was deliberately kept low [13] in order to save bandwidth for county viewers outside the campus with low bandwidth network access. Additionally, H.261, the video compression scheme used for the bulk of these streams, is mainly designed to produce low bitrates.

4. Trace Access Analysis

The trace that we analyzed was derived from the logs of the mMOD video web server. These logs recorded accesses to mMOD files from 29th of August, 1997 to 10th March, 1998 - little more than six months. Our first step, the removal of excess and erroneous requests from this raw data, is reported in section 4.1. We divide our subsequent investigation of the refined data into two broad parts:

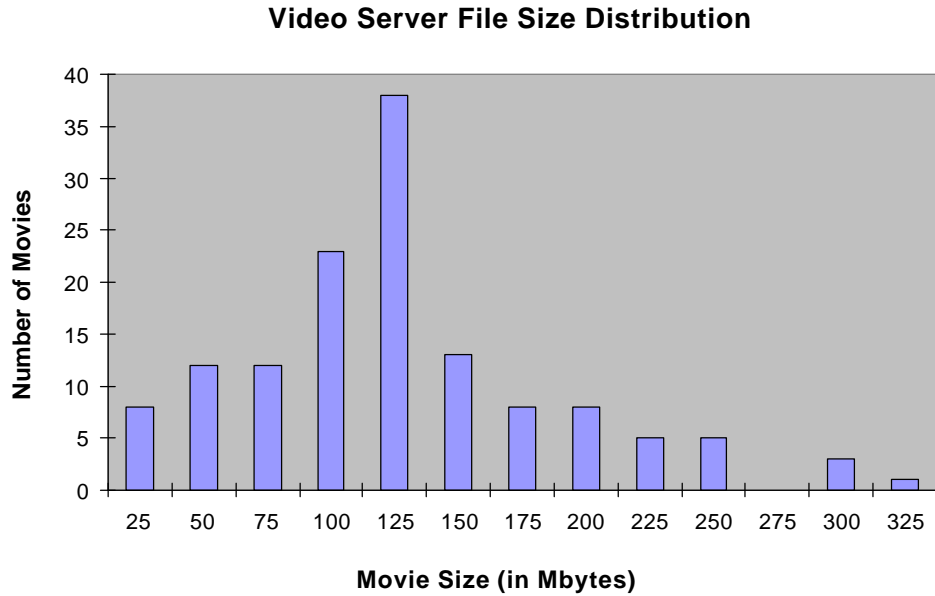


Figure 2: Video Server File Size distribution

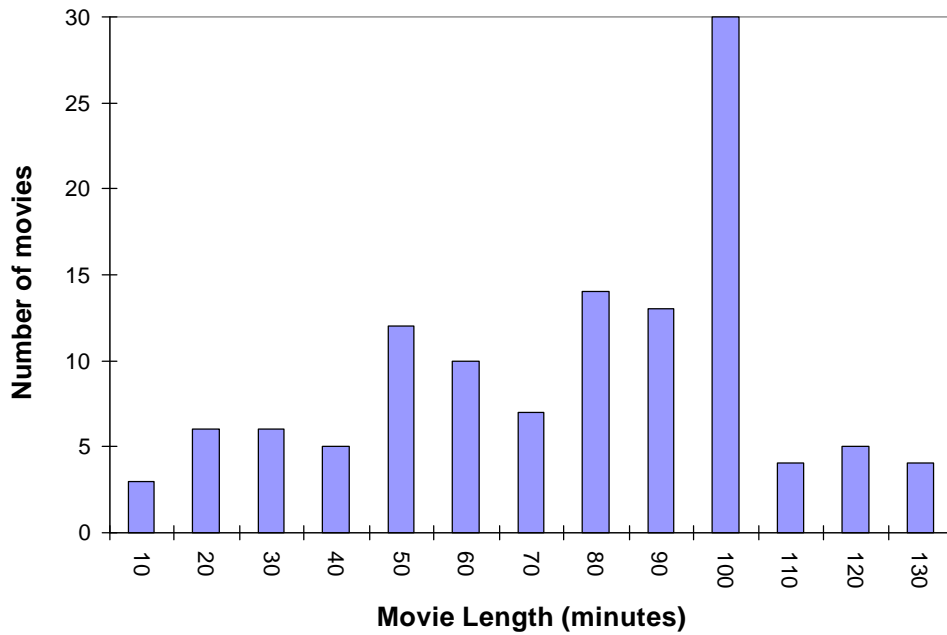


Figure 3: Movie Duration Distribution

- **General:** How do video requests vary by day (4.2)? Do accesses to movie titles follow any specific mathematical distributions (4.3)? Do some machines request more often than others (4.4)?
- **Pattern Detection:** Are there any patterns in inter-access times of user requests (4.5)? Do users view titles all the way through or do they stop beforehand (4.6)? Do accesses vary depending on the type of file (4.7)? Do requests exhibit any degree of temporal locality (4.8)?

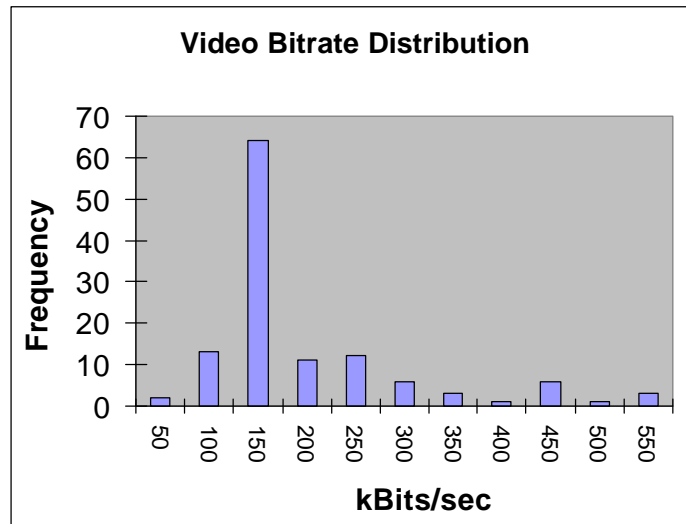


Figure 4: Video Bitrates

4.1 Initial Log Filtering

The requests logged by the mMOD web server can be classified as follows:

1. *Starting a video playback session:* the user requests the setup of the appropriate video transmission environment (a multicast/unicast group) for a certain file. Playback starts from the beginning of the file by default - however the VCR applet can be used to fast-forward or rewind as necessary.
2. *Stopping a session:* the web server halts transmission and removes the multicast/unicast group dedicated for the transmission of this file.
3. *Joining a session already in progress:* the user joins the multicast group devoted for the transmission of this title.
4. *Obtaining HTML documents.*
5. *Retrieving images.*

Of these, we eliminated types 3-5 from the initial logs. We ignored session joins (type 3) as, in practice, users rarely used this facility. The remaining two event types (4, 5) were irrelevant to our study. The distilled log consisted of the following entries:

```
<timestamp> <machine-name> <command> <title>
```

<timestamp> was the time, in seconds, when the request was made. *<machine-name>* indicated the originating machine. *<command>* was either GET or STOP, depending on whether the user wanted to commence or halt a video playback session. Finally, *<title>* gave the name of the movie desired. A sample log is shown below:

```
02:01:33 salt.cdt.luth.se GET Movie1
02:03:23 spock.cdt.luth.se GET TVSerial_970206
03:04:12 aniara.cdt.luth.se GET Movie2
03:10:11 aniara.cdt.luth.se STOP Movie2
```

After this initial cleanup, we performed further filtering on the simplified trace, including:

1. Eliminate all requests from a particular machine which had been used for demo purposes and hence would have had unusual access patterns.
2. Remove dangling STOPs caused by the user hitting the STOP button too many times.

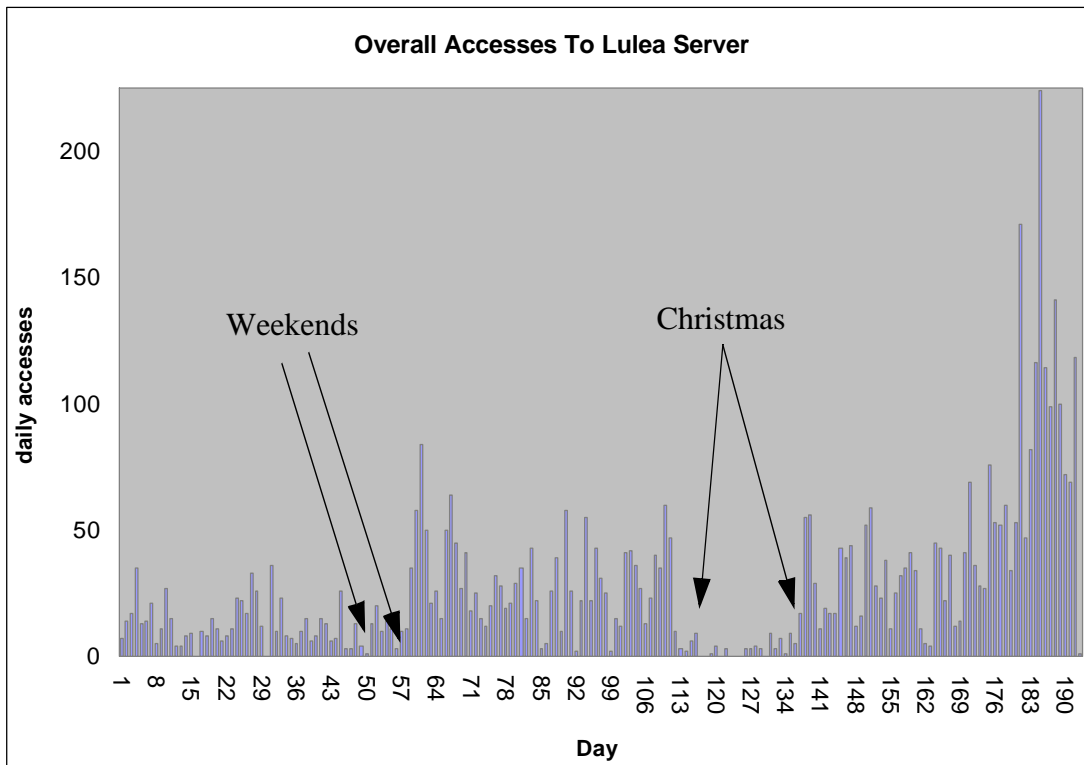


Figure 5: Accesses To Video Server Grouped By Day

3. Some machines in the trace were only identified by their IP addresses. We replaced the IP addresses by their symbolic names.
4. Ignore consecutive GET requests from the same machine for the *same* movie if they are within 20 seconds of each other. For example, in the case of:

```
02:01:01 aniara.cdt.luth.se GET Movie3
02:01:15 aniara.cdt.luth.se GET Movie3
```

the time difference between two requests is 14 seconds, hence the first request is ignored. The assumption is that there were problems in getting the first request to run and that is why the user started another request for the same movie. For time gaps more than 20 seconds, we assumed that the user genuinely wanted multiple streams of the same movie possibly because the same machine had multiple users or the user was editing this particular title. If, on the other hand, the first request had a corresponding STOP like the following:

```
02:01:01 aniara.cdt.luth.se GET Movie3
02:01:10 aniara.cdt.luth.se STOP Movie3
02:01:15 aniara.cdt.luth.se GET Movie3
```

then both requests were acceptable since the user had deliberately stopped the first request.

Steps 1 and 4 eliminated about 300 playback requests leaving 5249 accesses overall. We carried out our subsequent analyses on this trace.

4.2 Video Access Grouped By Day

Figure 5 plots six months worth of server access grouped in 24 hour periods. It shows a cyclic pattern of access that, with the exception of days 119-130, gradually increased with time. We found that accesses dropped off during weekends and rose again during the weekdays. Days 119-130 coincided with Christmas vacation when activity was mini-

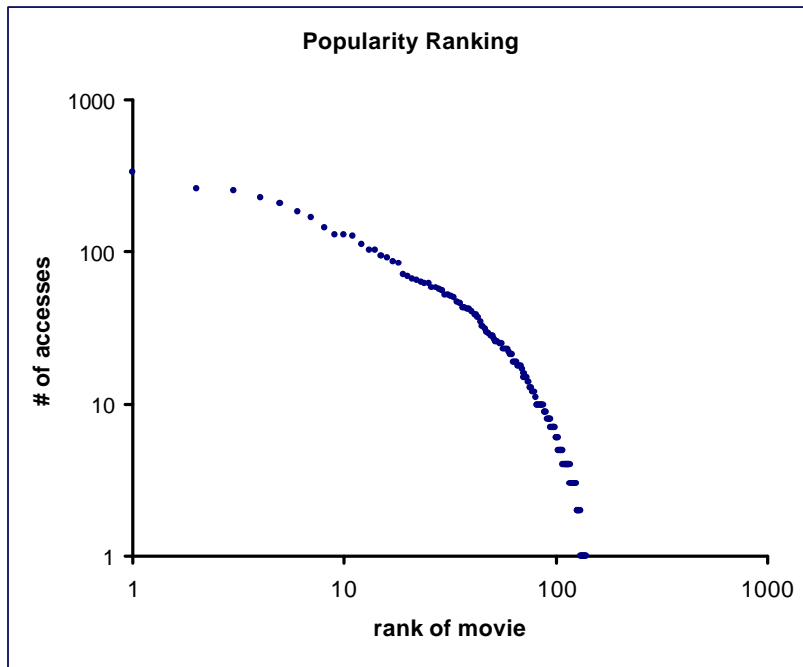


Figure 6: Log-Log Plot of Total Movie Accesses vs. Movie Ranks

mal. Finally, the number of accesses increased significantly post Christmas. This was due to more widespread deployment and usage of the mMOD system during the new semester, especially after the initial bugs had been ironed out.

4.3 Video Accesses To Movie Titles

Previous research on WWW traces [6] have shown that accesses to web documents tend to follow a Zipf distribution. Zipf's law [16], as applied to web access, states that given a collection of documents at a web server and a history of access to them, the frequency of access of a document (P) is related to its rank in popularity (p) by:

$$P \sim 1/(p^{1+t}) \text{ where } t = 0.27 \quad (\text{EQ 1})$$

This particular version of Zipf's law is based on a study of popularity followed by video store rentals [5]. Equation 1 implies if video accesses follow the Zipf pattern, then a logarithmic plot of video title ranking vs. their total number of accesses should show a straight line. Figure 6 indicates this is not the case. Instead, accesses to videos are even more biased towards popular titles than a Zipfian distribution - for example, the top ten percent ranked titles accounted for about 50% of all the accesses.

4.4 Video Accesses By Machine

The bulk of the machine accesses (67.4%) were local (i.e., originated from the campus). Most of these local accesses (63.5%) came from three subnets: *cdt.luth.se* (16.0% of total accesses), *sm.luth.se* (30.1%) and *campus.luth.se* (30.8%). Investigating further, we found that a small number of machines accounted for most of the video requests, thus indicating high spatial locality. For example, the top ten percent of the most active machines accounted for about 59% of the total requests and the top twenty percent generated about 74%.

4.5 Inter-access Arrival Times Distribution

In an attempt to detect any patterns in request arrival times, we plotted the distribution of inter-access times of the entire request series. This is shown in figure 7. We found the median inter-arrival time to be 411 seconds. With the exception of the observation that time between requests tend to be on the order of minutes, no other clear indications

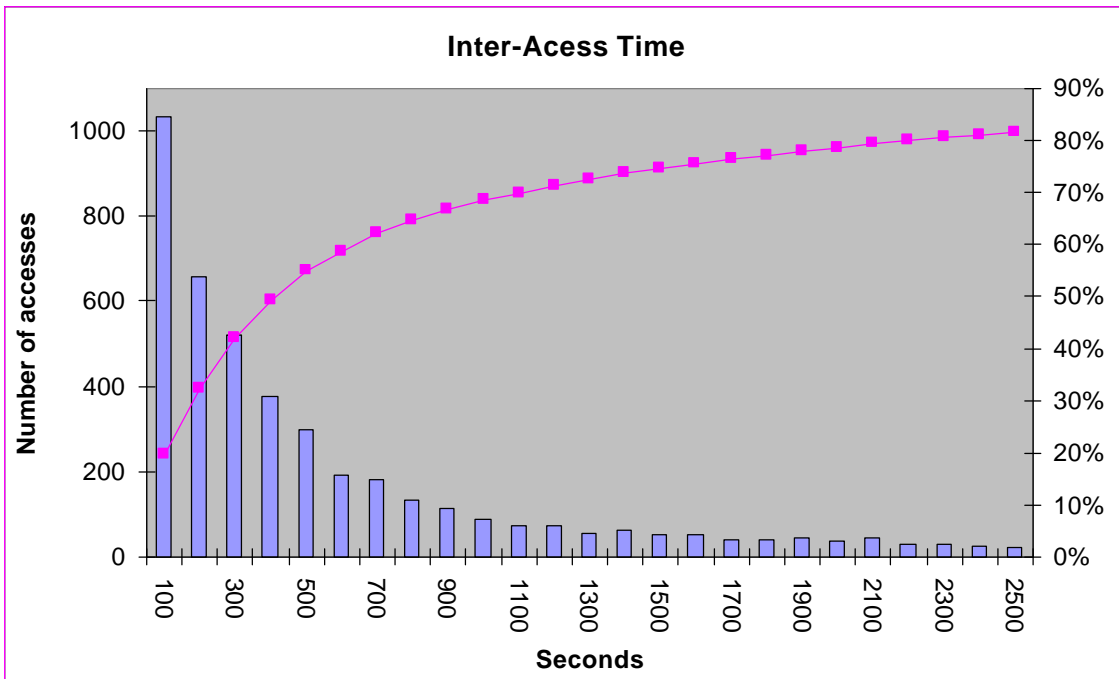


Figure 7: Inter-arrival Time Distribution

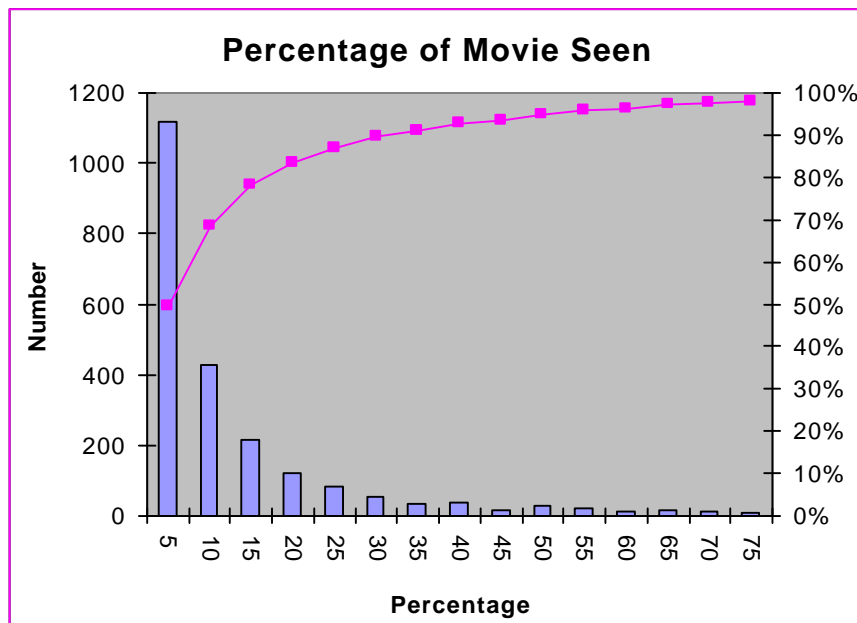


Figure 8: Degree of Partial Playback

emerged from this plot.

4.6 Partial Accesses

Not all of the playback sessions in the trace went all the way to completion. Assuming that a GET request without a

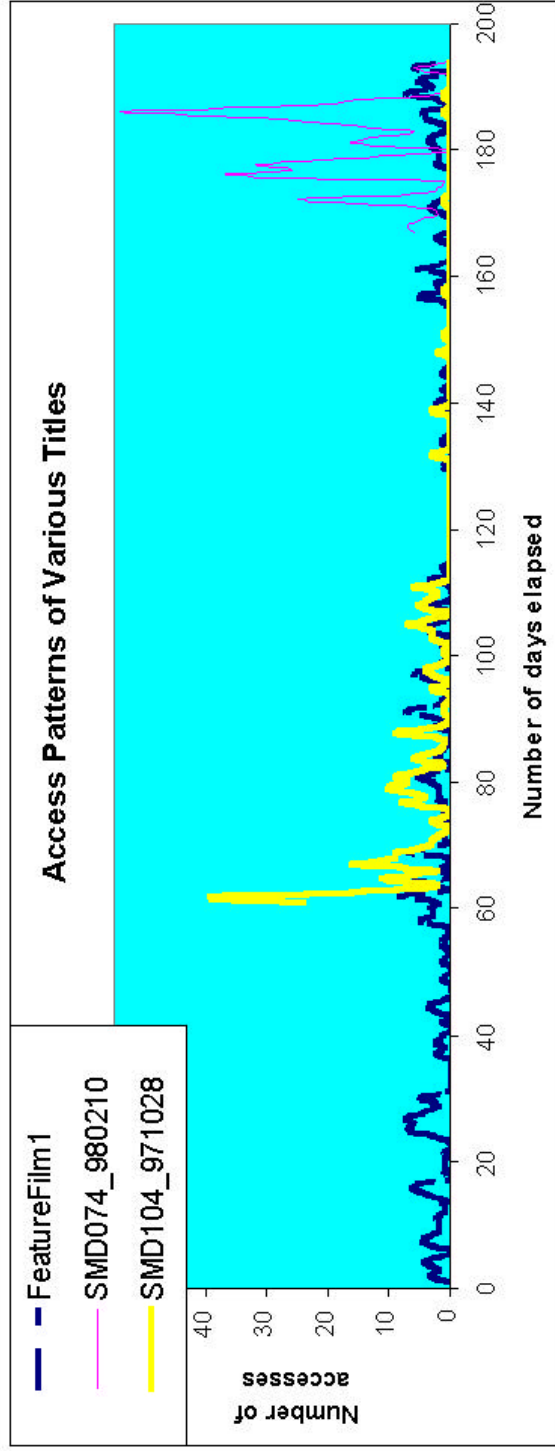


Figure 9: Differences in Access Patterns Between the Two Categories

matching STOP meant the user viewed that title all the way through, we found that about 55% of all requests played the entire duration. Figure 8 summarizes the degree of movie playback (before stoppage) for the remaining 45% requests as percentage of movie duration. Most stoppages occurred during the first 5% of the movie playback period.

4.7 Access Patterns Vs. Type of Title

The titles hosted by the mMOD server fell into two categories -- *general* and *educational*. The former type involved sort of entertainment or movie. The latter category included recordings of course-lectures, meetings and seminars. A total of seven titles (5% of the total number of titles) were available in the general section. Overall, general titles accounted for 12.3% of the total number of accesses. Table 1 breaks down the types of videos accessed in the three subtraces.

Table 1: Percentage of Accesses Accounted By General Titles

<i>cdt</i>	<i>campus</i>	<i>sm</i>
14.8%	14.0%	8.2%

Additionally, we found that accesses to general titles tended to be evenly distributed with time, whereas educational clips exhibited very high accesses over a smaller period. For instance, the popularity of material associated with a particular course would be likely to rise on the eve of homework assignments and prelims but die down shortly thereafter. Figure 9 provides some examples of this trend. Accesses to “FeatureFilm1” are spread out over the entire time period covered by the trace. In contrast, accesses to “SMD074_980210” and “SMD104_971028,” the former being a recording of a single lecture from a Distributed Multimedia course and the latter, an Object Oriented Programming lecture, show considerable variation over a relatively short period of time.

4.8 Temporal Locality Analysis

Temporal locality refers to the notion of the same document being re-referenced frequently within short intervals. We used the standard LRU (Least Recently Used) stack-depth analysis [3] of the trace to measure locality. In LRU stack-depth analysis, when a title is initially referenced, it is placed on top of the LRU stack (i.e. position 0), pushing other documents down the stack by one location. When the document is subsequently referenced, its current location in the stack is recorded, and the document is moved back to the top of the stack, pushing other documents down as necessary. After the entire log has been processed in this fashion, temporal locality is indicated if the top few positions in

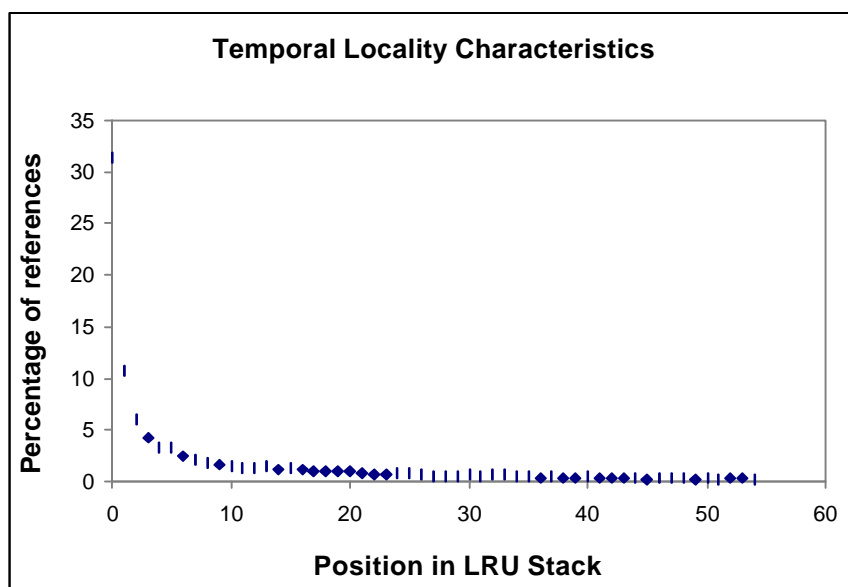


Figure 10: Results of LRU Stack-depth Analysis

the stack account for the bulk of the cumulative references. Figure 10 shows the analysis results. The top few positions in the stack account for a majority of overall references, thus indicating that the data does indeed display high temporal behavior.

5. Related Work

In the absence of any prior surveys of video access over the web, closest related work can be classified into roughly two types: examination of Web traffic and video access analysis for video on demand systems. Web traffic investigations can deal with requests either emanating from a cluster of clients or directly at the server itself. Mogul [11] and Kwan [9] have investigated access patterns at specific servers. In addition to analyzing the underlying systems and network behavior of the server under study, they also examined incoming HTTP requests by looking at their interarrival times, variations with time, size and type of files desired, and requesting domain type. The same core criteria (plus some others) were used by Arlitt [4] to extract underlying patterns from a number of server traces. Cunha et al [6] performed client side traffic work. They instrumented browsers at clusters of workstations to collect individual user access traces, which they then collated and analyzed. In all of these studies, videos accounted for a very small percentage (less than 1%) of overall requests. However, since the traffic data in these studies were all collected during 1994 and 1995 when the web presence of videos was insignificant, they do not present an accurate picture of current video activity.

Most recent video on demand models rely on results reported in two studies: Chervenak [5] and Dan, Sitaram and Shahabuddin [7]. These analyses examined statistics in magazines for video rentals and reports from video store owners. Both studies concluded that the popularity distribution of video titles could be fitted to a Zipfian distribution.

6. Conclusion

From the analysis of file characteristics, we found that content creators utilized low video bitrates when recording titles to disk. This allowed the capture of events with long durations such as classroom lectures and feature films at manageable, though still very large, file sizes. It also ensured that the bandwidth usage of the titles would be small during playback sessions, a useful feature for users accessing the system from outside the campus network. On the other hand, our trace analysis showed that viewers often accessed movies only partially. This observation, coupled with the high temporal locality present in the trace, indicates a type of *video browsing pattern* whereby a user might click on a title and let it run for a couple of minutes. If interested, the user lets it run to the end or he/she might stop the title, start it again from the beginning and then let it run to conclusion. If not interested, the user simply stops the playback session. Additionally, we discovered that the category of the movie also affected the type of reference pattern. Access to general titles tended to be even over a long period of time, whereas educational title accesses were more bursty over a shorter time period. Finally, our trace analysis exhibited a high degree of temporal locality, indicating that a cache based approach to improving video access performance could yield rich dividends. We incorporated our findings into the design of MiddleMan, a video caching web proxy system. Initial evaluations [2] show our architecture to be promising.

In the future, we aim to repeat our analysis methodology on traces from other VOW servers as well as logs from the mMOD server over a longer time period in order to verify our current findings and discover new patterns.

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