Redesigning the Online
Lecture Video Player to
Promote Active Learning
(Technical Paper)

Examining the Shaping of
Modern Content Deliver
Networks
(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Intro

As the internet has developed, video streaming has soared in popularity, becoming the dominant form of internet traffic in terms of bandwidth. Though streaming videos relies on the same basic data transfer techniques as text or images, the sheer volume of data consumed by videos continues to challenge the architecture of the internet, and the institutions that shape it. We now face difficulties in handling the sheer quantity of streaming data that is demanded, and in presenting videos in an engaging and informative manner. Understanding the challenges facing video presentation and distribution may allow us to better leverage the medium of videos to educate and entertain.

Technical Research Problem: Redesigning the Online Lecture Video Player to Promote Active Learning

How can a video player be designed to promote viewer engagement and learning?

Video lectures have become an increasingly common online resource of instructors and students alike. Most lecturers rely on common video hosting sites such as YouTube, or existing players to host and play their videos themselves. Teachers rarely have the time or reason to customize a video player, and often intend for students to attend lectures, with video recordings being used for review or missed classes. However, video lectures offer unique benefits not found in in-person lectures. Viewers can learn at their own pace through playback speed controls, pause or rewind to better take in information, and quickly search through the lecture for a specific topic or explanation. Though these basic tools come with most video players, we believe the student viewing experience can be further improved.

We aim to develop a custom video player that can better use the interactive aspects of videos to improve student's learning and interest. In order to help inform our design, we aim to first collect data from two sources: viewing behavior from interactions with the video player, and quiz data from an optional post-video quiz. This data will be collected from a variety of University of Virginia lecture videos. Both viewer behavior and quiz results will be continuously collected throughout the implementation of our player, and will be used to gauge the z. We have already identified different forms of viewer behavior, such as information seeking and continuous viewing that we will use to categorize the viewing habits of students. Understanding what kinds of behaviors are most common among student viewers, along with any correlation with quiz scores, will help us determine the types of features most important to improving lecture video players.

Our implementation for data collection consists of three distinct pieces: in-browser JavaScript to track events triggered by the user, an Application Program Interface (API) hosted on Heroku, and a Mongo database hosted on MongoDB Atlas. Interactions such as playing, pausing, or scrubbing through the video are tracked by the in-browser JavaScript, reported to the API, and saved in the Mongo database. Quiz results are also recorded, though they do not factor into a student's grade in their course, and are solely intended for judging any impacts of the video player. To help protect student anonymity, a minimum of identifying data is collected: no names, locations, IPs, or browsers are tracked, though the time at which each event occurs is recorded in order to build a timeline of events which can be further analyzed. We plan to compile individual timelines into watch profiles for each hosted video, allowing us to identify sections of the video that are commonly skipped, paused, or otherwise interacted with. Providing this information to professors may enable them to identify sections that students find confusing, as well as places where they disengage.

We hope the project will uncover insights into viewer behavior and spark interest in improving the viewing and learning experiences of lecture video viewers. Additionally, we hope the created prototype will be useful to current students and professors at the University of Virginia.

STS Research Problem: Examining the Shaping of Modern Content Delivery Networks

How has the rise of large-scale video content providers and the content distribution networks they require influenced the overall structure of the internet and the roles of the internet service providers that comprise it?

Introduction

As video content providers such as YouTube and Netflix increase in popularity, they inevitably must find ways to scale their services to a growing number of users. However, upscaling is not solely the responsibility of the video content provider: a successful large-scale content provider requires an enormous system of third-party content delivery networks and internet service providers (ISPs) in order to reach their end users. ISPs provide the infrastructure for connecting users to content, often through connections to numerous other ISPs. Content delivery networks give content providers access to a variety of ISPs: instead of negotiating for access to each ISP individually, a content provider can choose to have its content delivered through a content delivery network with an established relationship with various ISPs. These systems are becoming increasingly critical with the continued increase in demand for high volume data transfer: a trend that is likely to continue with the spread of 4 and 8k videos, as well as the declining usage of lower resolutions such as 240, 360, and 480 dpi (Kokaram, Foucu, & Hu, 2016). Understanding how the conflicting interests of video content providers, internet service providers, and customers have shaped and been shaped by large scale content delivery networks will help explain the current structure of the internet and the ways in which it may likely transform.

Background

In this system, disagreements often stem from the flow of data between the primary groups: large scale video content providers, internet service providers (ISPs), and viewers of video content. Video content, especially 4K video, requires a much larger internet bandwidth than regular site browsing. This can prevent users with slower internet speeds from streaming higher quality video content, but also causes tensions between companies like Netflix which supply this content, and the ISPs that have to transport it. As such, video content providers must negotiate with ISPs to carry this flood of data, whether directly or through content delivery networks (Carisimo, Selmo, Alvarez-Hamelin, & Dhamdhere, 2018).

In order to reach all internet users, content providers must connect to Tier 1 ISPs through transit networks, as seen in Figure 1. Doing so makes their content available to all of the Tier 2 ISPs that connect to the same Tier 1 ISP: these Tier 2 ISPs then make this content available to their users. Critically, Tier 1 ISPs creating peering networks with each other, allowing them to share access to their respective Tier 2 ISPs. By definition, Tier 1 ISPs have access to the entire internet through their peering networks. This peering network among Tier 1 ISPs acts as the backbone of the internet. In this way, by connecting with a Tier 1 ISP, a content provider makes their content accessible to the whole of the internet.

Incidentally, Tier 2 ISPs will also form peering relationships with each other, though instead of exchanging access to other ISPs, they exchange access to users. These peering relationships are beneficial to Tier 2 ISPs for two primary reasons. Firstly, if users can connect to each other without having to be routed through a Tier 1 ISP, their connection will be more direct and faster, creating a better experience to their users. Secondly, Tier 2 ISPs must pay to send data over transit networks to Tier 1 ISPs, while forming a peering network with another Tier 2 ISP is often done for mutual benefit and is free, aside from infrastructure and maintenance costs.

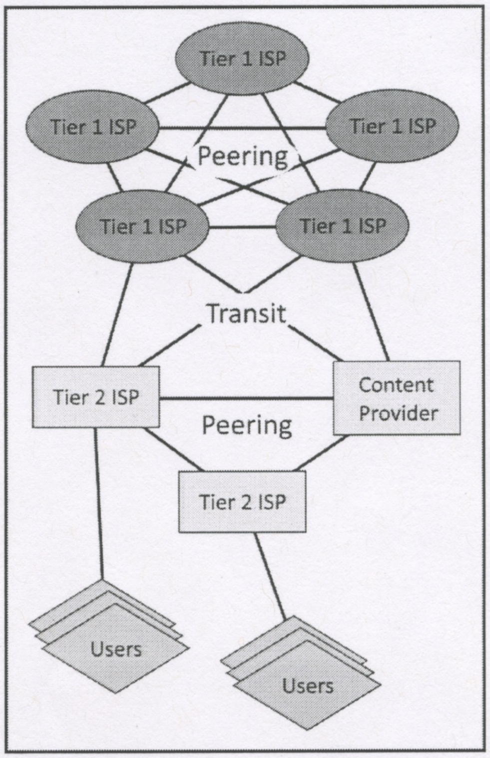

Figure 1.
Internet Transit and Peering

Similarly, content delivery networks and large-scale content providers will sometimes seek to form peering relationships with Tier 2 ISPs. Both benefit from peering for the same reasons that Tier 2 ISPs do: reduced latency and costs. Content providers often find the hardware and development costs of peering with Tier 2 ISPs lower than the cost of relying solely on transit networks with Tier 1 ISPs, despite a trend towards lower transit costs. Forming peering relationships with Tier 2 ISPs directly can also allow content providers to avoid paying and negotiating with third party content delivery networks to do so on their behalf.

However, the growing pains of upscaling affect video content providers in unique ways. As peering relationships typically form between ISPs of similar scales and impose no price on either party for transmitting data, a relatively balanced flow of data from each party is expected. However, viewing videos, especially full shows or series in higher resolutions, requires requesting an unusually large amount of data from content providers while sending little in return. This imbalance of network traffic can cause tensions between content providers and ISPs. As such, content providers will sometimes pay some sort of fee to help offset the imbalance of data transfer (Krogfoss, Weldon, & Sofman, 2012).

Instead of engaging in paid peering, Netflix has largely sought ISPs willing to peer for free through their content delivery network, Open Connect. Under Open Connect, Netflix supplies ISPs with a physical copy of the Netflix catalogue, known as an Open Connect Appliance. Browsing for shows and user analytics is still managed by Netflix's servers, but the content of the videos can be sent from the Open Connect Appliance (Netflix, 2019). Developing a specialized delivery system such as Open Connect, though costly in development and hardware, eliminates the need for a third-party content deliverer, and allows them to engage with more cheaper peering relationships with ISPs (Böttger, Cuadrado, Tyson, Castro, & Uhlig 2018).

The reception from ISPs has been somewhat mixed. ISPs want to improve their service to users, while maintaining favorable deals with video content providers and other ISPs, but their methods for achieving these goals varies by their regional dominance and customer loyalty (Ma, 2017). As such, attitudes towards Netflix and other large content providers vary among ISPs. In general, smaller, more competitive ISPs tend to peer with Netflix, as doing so enables them to provide their customers more reliable access to Netflix's content, while larger, established ISPs, such as Comcast, have opted for negotiating paid peering relationships outside of Netflix's Open Connect program.

Viewers are generally looking for reliable access to content, but also care about factors such as video quality, buffering, and price. As such, peering can be an attractive prospect, as it brings the content closer to the end users, increasing reliability. Whether peering benefits viewers economically is a more contested matter. Payment neutral peering, though once considered beneficial to both content providers and ISPs, has become a net burden on ISPs. Though peering reduces the costs of paying for transit with Tier 1 ISPs, it effectively increases the number of users the ISP must support (Krogfoss, Weldon, & Sofman, 2012). For example, if ISPs A and B are peering, and ISP A starts to peer with Netflix, then ISP A is likely to see an increase in traffic coming from ISP B users as they begin to access Netflix through ISP A. Viewer choice in ISP, while often quite limited, also impacts the socio-technical system through sparking competition and creating a spectrum of different environments in which a content delivery system must operate.

Through examining how these groups and their roles have evolved from before the rise of large-scale video content providers, I hope to discover the ways in which video content distribution has influenced and been influenced by the structure of the internet. Additionally, I hope to explore the impacts video content delivery has had on the wider structure of the internet, as the impact of the peering connections often desired by video content providers extends beyond large-scale video content delivery.

Data Collection and Analysis

For evidence of the influence of video content delivery systems on the structure of the internet, I will look to observed trends in internet development, such as the 'flattening' of the internet (Böttger, Cuadrado, Tyson, Castro, & Uhlig 2018). I hope to investigate the proposed causes of such trends in order to gauge the influence of content delivery networks on these trends. This in turn will help expose the ways in which video content delivery systems have influenced overall internet development.

To further examine the changing roles of ISPs in the structure of the internet, I will examine trends in peering. In particular, I hope to examine peering between Tier 2 ISPs, as well as between content providers and Tier 2 ISPs. If Tier 2 ISPs have changed their peering behavior in response to programs such as Netflix's Open Connect Program, this will expose a shift in the role that both Tier 2 and Tier 1 ISPs play.

Finally, I will look to points of conflict between content providers and ISPs, such as the changing of peering arrangements. Exploring the reasons for such conflicts can illuminate how the desires of content providers and ISPs have shifted over time: for example, a disagreement over the price of a payed peering arrangement may indicate that peering has become more or less attractive. The results of such conflicts may then serve as a judge of how the system was influenced by the disagreement, exposing the ways in which both content delivery systems and the internet adapt.

Conclusion

By examining the mutual shaping of video content distribution and the structure of the internet, we can better model its current state, better use and plan internet infrastructure to support video content distribution, and perhaps predict some of the ways these systems may transform in the near future. Likewise, working to improve the presentation of videos may open new understandings into the capabilities of videos for education and engagement. By examining the ways in which videos are distributed and presented, we can better understand the challenges facing videos as a medium, as well as understand the potential the hold for education and entertainment alike. As one of the most prominent forms of web traffic on the internet, a clear understanding of video media is important to any model of the internet as a whole.

Bibliography

Böttger, T., Cuadrado, F., Tyson, G., Castro, I., Uhlig, S.. (2018). "Open Connect Everywhere: A Glimpse at the Internet Ecosystem Through the Lens of the Netflix CDN". *ACM SIGCOMM Computer Communications Review (CCR)*, 48(1). Retrieved from http://arxiv.org/abs/1606.05519

Carisimo, E., Selmo, C., Alvarez-Hamelin, J. I., & Dhamdhere, A. (2018). Studying the Evolution of Content Providers in the Internet Core. *2018 Network Traffic Measurement and Analysis Conference (TMA),* 1–8. https://doi.org/10.23919/TMA.2018.8506513

Kokaram, A., Foucu, T., & Hu, Y. (2016). A look into YouTube's video file anatomy. Retrieved October 4, 2019, from YouTube Engineering and Developers Blog website: https://youtube-eng.googleblog.com/2016/04/a-look-into-youtubes-video-file-anatomy.html

Krogfoss, B., Weldon, M., & Sofman, L. (2012). Internet architecture evolution and the complex economies of content peering. *Bell Labs Technical Journal, 17*(1), 163–184. https://doi.org/10.1002/bltj.21529

Netflix. (2019). Open Connect. Retrieved December 12, 2019, from https://openconnect.netflix.com/en/

Ma, R. T. B. (2017). Pay or Perish: The Economics of Premium Peering. *IEEE Journal on Selected Areas in Communications, 35*(2), 353–366. https://doi.org/10.1109/JSAC.2017.2659038