DESIGNING MODERN WEBSITES FOR LOW-THROUGHPUT NETWORKS

OVERCOMING LOW BANDWIDTH IN AN INCREASINGLY ONLINE EDUCATIONAL WORLD

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By
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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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The ability to provide a smooth user experience while lacking basic information about the end user's device is one of the overarching challenges that comes with designing applications for the web, and there are a wide variety of issues that fall under its umbrella. One of the primary challenges is that the time it takes for data to be delivered from a server to the end user is not constant across devices, regions, or even home networks. This is because the speed at which a website loads is directly related to the strength of the network, the efficiency of the user's home Wi-Fi (if they are even using Wi-Fi), and the quality of the device through which it is being accessed. The current state-of-the-art solutions for this problem will be examined in the technical report.

This problem can also be examined from another perspective: that of the end user. If a user has a lower-end computer or Wi-Fi network, they face disadvantages when compared to other users. Data will load more slowly, and depending on their device's processor strength they may be completely unable to interact with the Internet in the same form as their peers with high-end devices. In the context of online classrooms in America, like those that were created in the midst of the COVID pandemic, this can lead to certain groups of students being unable to properly interact with the course material. This sociotechnical problem and its potential for effectuating social stratification will be analyzed in the STS research project.

The two problems that have been outlined are tightly coupled. The technical topic examines the challenge posed by low-throughput networks to web engineers, and the STS topic complements it by looking at the social implications of the same problem from the side of the end user. This close relationship between the two will allow for a comprehensive investigation of both through the interplay of technology and society.

DESIGNING MODERN WEBSITES FOR LOW-THROUGHPUT NETWORKS

Increasingly, access to the Internet is being debated as "a human right in and of itself" (Peacock, 2019, p. 4). However, simple access to a network is not enough. Users also need *reliability*, which comes in terms of high throughput and low latency. Throughput is the capacity of the network to deliver information to a device, while latency is the tangible delay in response that occurs while a device loads a website (Feamster & Livingood, 2020). If a network has a high throughput level, it means that it is able to transfer large amounts of data at one time. If it has low latency, it means that information travels quickly from source to destination. In Figure 1, the basic flow of data through the Internet has been outlined. It is important to note that a request can travel through multiple networks on its round-trip back to the client's browser.

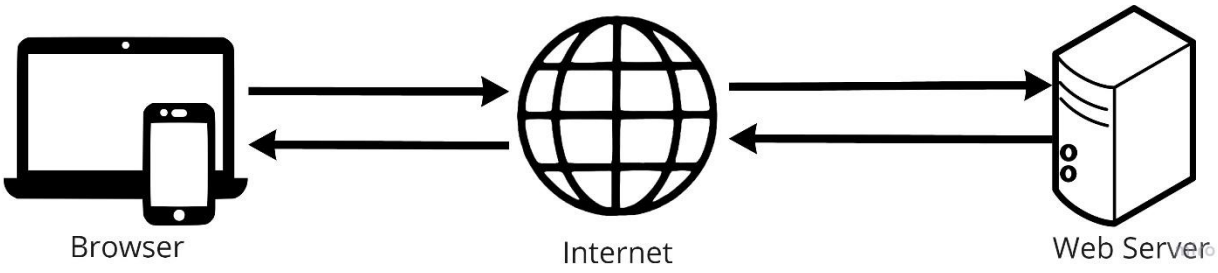

Figure 1: Lifecycle of a Web Request. When a browser requests information, it must travel through the Internet to a web server, and then return to the browser before the webpage can load (Helmrath, 2021).

From the perspective of a web developer, network throughput is a given and cannot be changed. Therefore, the only metric they can improve is latency, which is possible by minimizing the amount of data they need to send over the network. This is why latency is considered the "key bottleneck of user-perceived performance" when it comes to webpages (Xue et al., 2017, p. 2). It is the most visible metric to the end user and also the metric that can be tuned the most by web developers. The technical report will focus on the developer's ability to regulate and reduce latency on their website.

When a webpage is first accessed, it can load many different resources from many different destinations. As illustrated in Figure 1, for each of these requests the browser must interface via the Internet with different servers. Each of these requests takes place in different physical networks, possibly over different countries depending on the locations of the web servers. These requests are not responding with just text and images, but also script files and other pieces of data that the user never interacts with (Mozilla, 2021). Providing a consistent web experience despite the wide variety of latencies caused by the variety in files and network locations is not a simple problem to solve, and there are many schools of thought when it comes to potential solutions.

Some developers propose that load times can be improved by taking advantage of edge caching. This is the process of storing popular files in multiple servers across the globe, choosing the server with the lowest latency to the end user. Through this method, "users can get requested contents with [a] one-hop wireless transmission" as opposed to traveling through multiple different networks for a single request (Lyu et al., 2021, p. 1). Others advocate for lazy loading, which is the concept of loading resources in their entirety but delaying this load until the moment that you *absolutely* need the information (Bendell et al., 2016). Already, it is easy to see that this a problem with no agreed-upon solution. As the field continues to expand, the variety of solutions only becomes wider.

The state-of-the-art technical report, to be completed in the Spring of 2022, will examine this problem through a survey of the solutions present in currently available research and literature. It will highlight current solutions that are being implemented by industry leaders, and also look ahead to possible solutions that are in the process of being researched. The aim of this

research is to provide a basic guide for web developers to use when considering which of these solutions to use in their own projects.

OVERCOMING LOW BANDWIDTH IN AN INCREASINGLY ONLINE EDUCATIONAL WORLD

After investigating how web developers work around low-throughput networks, the STS research paper will examine how low-throughput networks affect end users. Specifically, the paper will seek to answer the question of how low-throughput conditions affect students participating in online classes, and whether or not those conditions serve to create divides between various social groups.

The switch to a majority online-only world during the COVID pandemic exacerbated the widening of the opportunity gap between those with access to reliable Internet and those without. Assignments which were once handed out and submitted in class via hard copies are now posted exclusively online, with students expected to submit these through online file systems. Class itself is now no longer a physical location, but a link to a Zoom meeting that requires a stable Internet connection in order to listen to and interact with the material. When considering students in K-12, it brings into question how well the 17 million children without home Internet access can succeed (Federal Communications Commission, 2021). This paradigm shift in the way that students are expected to "go to school" has disadvantaged those who cannot afford, or simply do not have access to, a reliable connection.

Typically, schools and online courses lack the infrastructure to satisfy students of all Internet speeds. Instead, those with lower speeds struggle to view and submit assignments while those who can afford to pay for faster speeds get the attention that they need from their teachers

(Rai, 2018). According to a survey of Chinese junior high school students by Jing-Jing & Ming (2021), those of lower socioeconomic status (SES) had reduced academic scores, possibly due to a lack of access to the Internet. This divide is not solely due to SES, though – location also plays a part. In 2016, 39% of rural communities in the US "lacked access to true broadband", which is characterized by download speeds of 25 Megabits per second (McCoy, 2020, p. 44). However, even those regions with "true broadband" are not guaranteed to use it to its fullest extent. Figure 2 reveals that throughout the US, broadband availability does not correlate to broadband usage. Either due to pricing or infrastructure, Americans are not able to get the speeds that are expected of modern broadband networks.

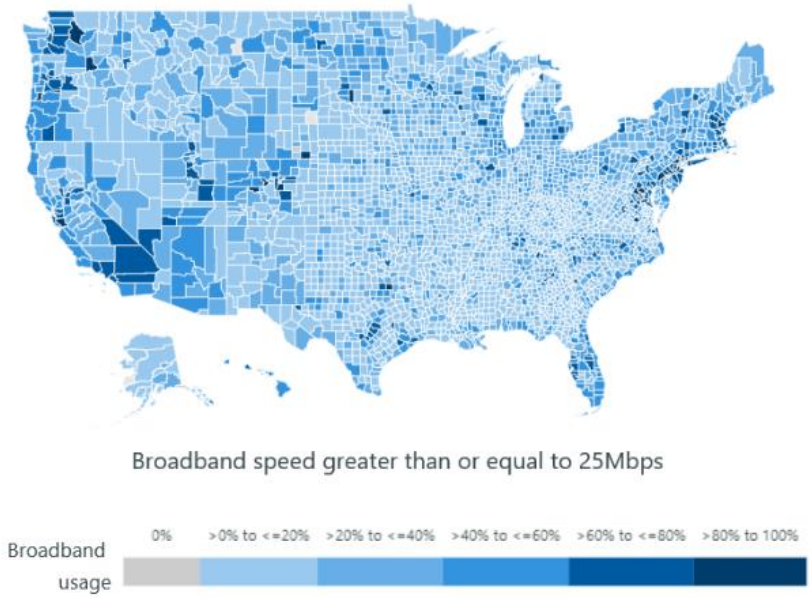

Figure 2: Heatmap of broadband usage in areas that have access to "true broadband" (Kahan, 2019).

This is a problem that educators have faced ever since schools began using the Internet to deliver course material. For example, Cook & Grant-Davis discuss the process by which they developed an online classroom for students around the globe. Even in 2005, they mention how they optimize their course material in order to ensure that students can access it efficiently, even without a high bandwidth connection. They explicitly state that one of their main goals while developing their course is to ensure that "students on both sides of the world are able to access their assignments and discussion materials with efficiency" (Cook & Grant-Davis, 2005, pp. 273–275).

While this problem has been around for as long as schools have used the Internet to deliver course material, it has never before existed at its current magnitude due to the COVID pandemic. Therefore, its effects have yet to be fully realized. The goal of this research project is to investigate how students are affected by low bandwidth networks, and how online educational websites and technologies can indirectly create divides between socioeconomic groups of students. This paradigm will be examined through the framework of Actor-Network Theory (ANT), an STS framework first proposed by Law & Callon (1988). ANT will help to demonstrate how actor relationships have served to shape current online educational tools and the society surrounding them. Figure 3 illustrates a basic network, along with the relationships between various human and non-human actors.

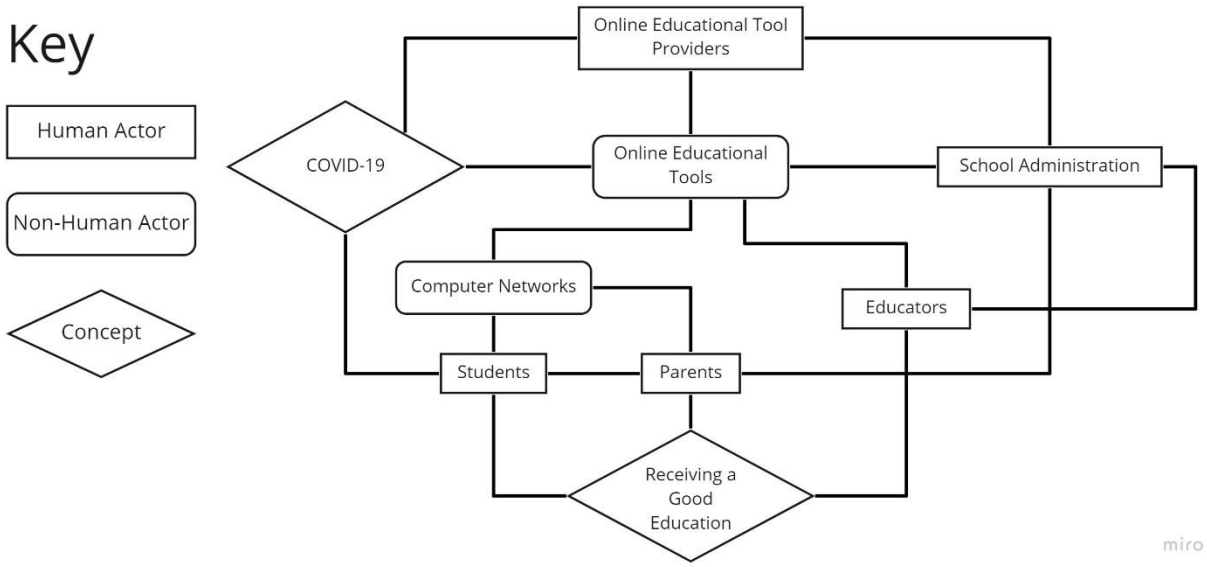

Figure 3: Online Educational Tool ANT Diagram. Visualizes the relationships between various human and non-human actors (Helmrath, 2021).

UNRELIABLE INTERNET: A PROBLEM EXAMINED FROM BOTH SIDES

Both the technical topic and the STS topic discussed in this paper address the issue of unreliable and low throughput networks. The technical paper will explore the current solutions and tools being used by industry professionals in combatting this problem. It will provide a summary of the state-of-the-art for web developers to use as a reference when determining how to solve these problems on their own. The STS research paper will analyze how students without the means to afford modern Internet technology, or those who live in regions with weak networks, are affected by their circumstances in the context of online educational tools through the ANT framework. Effectively, these papers will be able to demonstrate how two different groups of society, web developers and web users, seek to solve a common issue that negatively affects both: slow Internet speeds.

REFERENCES

Bendell, C., Kadlec, T., Weiss, Y., Podjarny, G., Doyle, N., & McCall, M. (2016). *High Performance Images.* Cambridge: O'Reilly Media, Incorporated. https://learning.oreilly.com/library/view/high-performance-images/9781491925799/

Cook, K. C., & Grant-Davis, K. (2005). *Online Education: Global Questions, Local Answers.* Taylor & Francis Group. https://ebookcentral-proquest-com.proxy01.its.virginia.edu/lib/uva/detail.action?docID=3117819

Feamster, N., & Livingood, J. (2020, December 1). Measuring Internet speed current challenges and future recommendations. *Communications of the ACM*, *63*(12), 72–80.

Helmrath, W. (2021). *Lifecycle of a Web Request*. [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Helmrath, W. (2021). *Online Educational Tool ANT Diagram*. [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Federal Communications Commission. (2021, July 22). *Homework Gap and Connectivity Divide*. https://www.fcc.gov/about-fcc/fcc-initiatives/homework-gap-and-connectivity-divide

Jing-Jing Chen, & Ming Fei Liu (2021, May 1). Does the Internet expand the educational gap among different social classes? The protective role of future orientation. *Frontiers In Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.647351

Kahan, J. (2019, April 8). *It's time for a new approach for mapping broadband data to better serve Americans*. Microsoft. https://blogs.microsoft.com/on-the-issues/2019/04/08/its-time-for-a-new-approach-for-mapping-broadband-data-to-better-serve-americans/

Law, J., & Callon, M. (1988). Engineering and sociology in a military aircraft project: A network analysis of technological change. *Social Problems*, *35*(3), 284–297. https://doi.org/10.2307/800623

Lyu, F., Ren, J., Cheng, N., Yang, P., Li, M., Zhang, Y., & Shen, X. S. (2021). LeaD: Large-Scale edge cache deployment based on spatio-temporal WiFi traffic statistics. *IEEE Transactions on Mobile Computing*, *20*(8), 2607–2623. https://doi.org/10.1109/TMC.2020.2984261

McCoy, R. (2020, April 1). Broadband connectivity in "Flyover Country". *Information Systems Education Journal*, *18*(2), 41–49. http://isedj.org/2020-18

Mozilla. (2021, October 3). *An overview of HTTP*. MDN Web Docs. https://developer.mozilla.org/en-US/docs/Web/HTTP/Overview

Peacock, A. (2019). *Human Rights and the Digital Divide*. Abingdon, Oxon: Routledge. https://doi-org.proxy01.its.virginia.edu/10.4324/9781351046794

Rai, L. (2018, October 1). Offline support model for low bandwidth users to survive in MOOCs. *International Journal of Emerging Technologies In Learning*, *13*(10), 270–277. https://doi.org/10.3991/ijet.v13i10.8595

Xue, J., Wang, J., Liu, S., Ma, X., & Wang, H. (2018, May 10). Dissecting persistent instability of web service: A joint perspective of server schedule dynamics and path latency.

International Journal of Communication Systems, *31*(7), Article e3441.

https://doi.org/10.1002/dac.3441