Cloud VR Thesis

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6 Introduction

Recent developments in the field of virtual reality (VR) offer all kinds of opportunities in the field of training and entertainment. For training purposes, the audiovisual entry into a virtual world is where the biggest value is. The capabilities of artificial environments allow users to manage scenarios and experiences that cannot be simulated in the real world. VR also allows users to access the virtual training at any time and less physical facilities are required for exercises. Examples VR experiences include training maintenance at high altitudes (such as windmills), working under heavy loads weather conditions in construction (Strukton) or maintenance on naval ships (Thales).

7 Preliminary Problem Statement

One of the essentials for a good VR experience is a powerful computer system to render semi-realistic worlds. However, there are two problems here. First, this type of system is not available in every location. Certainly if realistic images have to be rendered in the simulation, it requires specialized and expensive machines that are difficult to move.

The second problem is that for rendering the VR training scenario, all kinds of data about the scenarios need to be available on the system. This can pose a problem when it concerns sensitive information, for example about all kinds of information defense systems or business sensitive information.

Focusing on these problems will lay the foundation for future research, to make CloudVR streaming a mature technology.

The aim of this project is to investigate the feasability of a streaming based VR approach with current cutting edge technology. Qualitative research methods will be used to gain in-depth insights about existing solutions and the current state of research into this topic. The data will be contextualized via a literature review of recent research papers and an analysis of the capabilites of existing solutions when applied to the research problem.

8 Problem Analysis

Together with the companies from the Industrial Reality Hub mentioned in the Introduction, Saxion wants to investigate how virtual reality can be rendered in the cloud in a safe and efficient manner. This involves looking at state-of-the art technology in the field of virtual reality, cloud computing, rendering and machine learning for one complete CloudVR pipeline. There are four research objectives here:

8.1 Architecture for a cloud system

One of the questions to be answered is what the CloudVR architecture should look like in terms of hardware and software. This not only concerns the servers, but also whether there are local ones rendering is required (see the next point). Figure 1 provides an overview of a possible CloudVR solution displayed. Figure 1: Example CloudVR architecture.

8.2 Latency

Current market players such as Google Stadia, GeForce Now and Xbox xCloud already offer cloud gaming services that stream games over the internet. Powerful servers are used for rendering games that are then streamed to users in real time. A bottleneck with this technology is the latency (delay). This is because user input is first sent to a server sent, renders these new images after which they are sent back to users, this all without disturbing the users. The mentioned platforms all use network optimization. It is low latency However, very important for VR which head movements under 20 milliseconds 4 should be converted to image to prevent motion sickness. The research is for this techniques for reducing latency are one of the spearheads of the CloudVR project. The following research directions are relevant here:

Network optimization As with the platforms described above, network optimization is one of the techniques which needs to be investigated. The question is to what extent an optimized network can reduce latency and how it relates to the quality of the network connection.

Two-step rendering One of the options to bypass latency is to render in two steps. The delay is not so much reduced, but avoided. The server renders next to RGB also positions and BRDF variables for each pixel. Afterwards, the user, on less powerful hardware, adjustments are made so that the image corresponds to the current position of the user.

Behavioral prediction Another possibility to reduce latency is by predicting user input through machine learning. This will mainly revolve around it analyzing head movements to find out what behavior can be expected. With this information can render any part of the virtual world before it is viewed by users. If this information is then forwarded from the cloud to the location of the VR experience, what information can be selected on the spot is displayed.

8.3 Multi-user experiences

One of the questions with a CloudVR solution is how to deal with multi-user VR experience where user at another location to share a VR experience via a network. The interaction with each other and the environment a point of attention.

8.4 GPU scaling

One of the advantages of cloud rendering is that in theory it gives the possibility of unlimited computing capacity. This gives the opportunity to all kinds of touristic feats (graphic), and interaction (physics). It is therefore interesting as part of the CloudVR pipeline to investigate how techniques such as NVLink and NVSwitch 5 could be used for high-quality VR experiences.

9 Theoretical Framework

In order to thoroughly understand the aim and subject of the research, it is important to explore different existing solutions and literature. Therefore, the subjects that will be discussed in the following theoretical framework are Cloud Streaming/Cloud Computing and Virtual reality. Within this theoretical framework, definitions of the subjects will be given as well as current insights into these subjects. The topics reflect knowledge needed to understand the problem space. Together all of the topics make up the 360 scan.

9.1 Cloud Streaming/Cloud Computing

9.1.1 Definition

According to Armbrust et al. (2010) Cloud computing is defined as follows: "Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services." (Armbrust et al., 2010) We can then further define Cloud streaming as the applications that are delivered over the internet as a service.

9.1.2 Existing Solutions and Technology

Several commercial gaming Cloud streaming services already exist, such as Google Stadia (Google, n.d.-b), XBox XCloud (XBox, n.d.) and Nvidia GeForceNow (Nvidia, n.d.). There is also a variety of Infrastructure-as-a-service (IaaS) platforms, such as Amazon's AWS (Amazon, n.d.), Microsoft's Azure (Microsoft, n.d.) and Google's Cloud Platform (Google, n.d.-a).

9.2 Virtual Reality

9.2.1 Definition

10 Literature Review

10.1 Modern (<5 years old) research and technology

Within the last decade the cloud computing space has expanded rapidly and with it the possibilities. Today, even individuals can set up an experimental cloud VR streaming solution from pre-made components (TayoEXE, n.d.), such as the service from cloud computing company Shadow (Shadow, n.d.). The most recent years have also seen the rise of commercial cloud streaming for gaming services, such as Google Stadia (Google, n.d.-b), XBox XCloud (XBox, n.d.) and Nvidia GeForceNow (Nvidia, n.d.), but not without problems, as the services were quickly overwhelmed on launch. However no commercial products for cloud VR streaming exist at the time of writing, hence the need for this research paper. Modern video compression codecs, like the AV1 codec introduced in 2018 (for Open Media, n.d.), are getting better and better at compressing high-resolution video streams and together with an application like WebRTC (Google, n.d.-c) which offers latency optimizations via peer-to-peer networking and more, they lay the foundation for modern cloud streaming applications. With ever increasing performance and optimizations, the feasibility of cloud VR streaming is just a matter of time.

Research Papers like the ones from Liu et al., 2018 or from Shi, Gupta, Hwang, and Jana, 2018 demonstrate the viability and technical feasibility of cloud VR streaming . They developed innovative solutions to achieve and undercut the 20ms Motion-to-Photon (MTP) barrier while streaming VR content. 20ms is the agreed upon threshold a frame should have, from receiving the input to displaying the frame on the Head Mounted Display (HMD), to avoid inducing motion sickness. One such solution is a low latency control loop that streams VR scenes containing only the user's Field of View (FoV) and a latency adaptive margin area around the FoV. This allows the clients to render locally at a high refresh rate to accommodate and compensate for the head movements before the next motion update arrives. (Shi et al., 2018). Another angle of attack leverage's the power of parallel rendering, encoding, transmission and decoding, together with a Remote VSync Driven Rendering approach to minimize MTP latency (Liu et al., 2018). The prototype for this experiment was based on commodity hardware, which further demonstrates the feasibility of cloud VR streaming.

10.2 Older (>5 years old) research and technology

2010-2015 a lot of crucial standards were developed, that are being used today to power cutting edge cloud solutions.

11 Final Problem Statement

12 Research Questions

Main Question 1:

What is the current state of cloud VR streaming?

Sub Question 1: What cloud streaming solutions are already existing?

Sub Question 2: How effective are existing solutions when applied to the cloud streaming VR context?

Sub Question 3: What research has been done on the shortcomings from question 2?

Sub Question 4: Which issues still require the most research?

Main Question 2:

What are the best practices when building a cloud streaming VR pipeline?

Sub Question 1: What are the most important considerations when desiging an Architecture for cloud VR streaming?

Sub Question 2: What is the most efficient way to reduce MTP (Motion-to-Photon) Latency?

Sub Question 3: What is the best practice for multi-user experiences?

Sub Question 4: Does GPU scaling improve User Experience (UX)?

13 Methodology

14 Experiments

15 Results

16 Discussion

17 Conclusion

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