

# Cloud VR Thesis

Leon Koster

April 2020

# 1 Acknowledgements

## 2 Abstract

# Contents

<b>1</b>	<b>Acknowledgements</b>	<b>2</b>
<b>2</b>	<b>Abstract</b>	<b>3</b>
<b>3</b>	<b>List of Figures and Tables</b>	<b>5</b>
<b>4</b>	<b>List of Abbreviations</b>	<b>6</b>
<b>5</b>	<b>Glossary</b>	<b>7</b>
<b>6</b>	<b>Introduction</b>	<b>8</b>
<b>7</b>	<b>Preliminary Problem Statement</b>	<b>9</b>
<b>8</b>	<b>Problem Analysis</b>	<b>10</b>
8.1	Architecture for a cloud system . . . . .	10
8.2	Latency . . . . .	10
8.3	Multi-user experiences . . . . .	11
8.4	GPU scaling . . . . .	11
<b>9</b>	<b>Theoretical Framework</b>	<b>12</b>
9.1	Cloud Streaming . . . . .	12
9.2	Virtual Reality . . . . .	12
<b>10</b>	<b>Literature Review</b>	<b>13</b>
<b>11</b>	<b>Final Problem Statement</b>	<b>14</b>
<b>12</b>	<b>Research Questions</b>	<b>15</b>
<b>13</b>	<b>Methodology</b>	<b>16</b>
<b>14</b>	<b>Experiments</b>	<b>17</b>
<b>15</b>	<b>Results</b>	<b>18</b>
<b>16</b>	<b>Discussion</b>	<b>19</b>
<b>17</b>	<b>Conclusion</b>	<b>20</b>
<b>18</b>	<b>Appendices</b>	<b>22</b>

### **3 List of Figures and Tables**

## 4 List of Abbreviations

## 5 Glossary

## 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 feasibility 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 capabilities 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 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 and Virtual reality. Within this theoretical framework, definitions of the subjects will be given as well as current insights into these subjects. The reason why these topics are chosen is because they are crucial to the project and its identity.

### **9.1 Cloud Streaming**

#### **9.1.1 Definition**

### **9.2 Virtual Reality**

## 10 Literature Review

## 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 designing 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

## References

- Google. (n.d.). *Stadia - one place for all the ways we play*. <https://stadia.google.com/> (accessed: 11.05.2020)
- Nvidia. (n.d.). *Your games. your devices. play anywhere*. <https://www.nvidia.com/en-us/geforce-now/> (accessed: 11.05.2020)
- XBox. (n.d.). *Project xcloud*. <https://www.xbox.com/en-US/xbox-game-streaming/project-xcloud> (accessed: 11.05.2020)

## 18 Appendices