Paper 1: "Reducing Visual Discomfort with HMDs Using Dynamic Depth of Field" by Kieran Carnegie and Taehyun Rhee; Victoria University of Wellington, New Zealand.

Paper 2: "The Effect of Out-of-focus Blur on Visual Discomfort When Using Stereo Displays" by Tobias Blum, Matthias Wieczorek, Andr´e Aichert, Radhika Tibrewal, Nassir Navab.

- **This is a review about the two papers mentioned above. They mainly focus on the advancements in "Virtual Reality software and technology".**

The advent of consumer stereoscopic Head-Mounted Displays (HMDs) like Oculus Rift opens up hitherto unexplored ways to use them in VR/AR applications. However, 80 percent of users still report adverse physical discomfort or "simulator (motion) sickness" when using such devices. Basically Visual discomfort is a major problem for head-mounted displays and other stereo displays. One effect of that is known to reduce visual comfort is double vision, which can occur due to high disparities. In the last few years, numerous researches on improving the vision quality through Virtual Reality-based Systems have appeared.

The first paper "Reducing Visual Discomfort with HMDs Using Dynamic Depth of Field" by Kieran Carnegie and Taehyun Rhee when summarized can be said that it's about the advancement use of blur effects in decreasing viewer discomfort. Depth of focus blur effects has been studied not only for general visual discomfort as well as symptoms such as fatigue, headache, and eyestrain. Their study shows that DoF blur can considerably alleviate most of these discomforts, thereby reducing simulator sickness on the whole. This work has the potential to advance the widespread adoption of VR. The author considers the previous studies on visual discomfort and considering the approaches of previous studies an effective system for reducing the blur has been developed. Author has concluded that, we can Reduce Visual Discomfort by viewing monoscopic or stereoscopic content with a small angle of difference between the two images. Removing and/or minimizing the vergence cues for depth and distance estimation also reduces discomfort. Other attempts to explicitly solve the accommodation–vergence conflict in stereoscopic displays have also used hardware-based approaches involving setups such as multifocal displays, alternative lens systems, or multi lens systems. Their system was constructed to meet the conditions like reducing the amount of focusing a user needs to perform and reducing the range of virtual depths on which a user must focus. For general stereo displays (such as an LCD), limiting eye movement to only focusing on the center of a screen will limit users' spatial degrees of freedom. However, in HMDs, the majority of spatial movement will occur through head movements rather than through eye movements, compensating for this drawback. Effects such as variable acuity resolution on the Oculus, where central pixels are of a higher perceived density, also serve to drive user focus away from the periphery, limiting the effect of DoF blurring on peripheral information.

for Each pixel p_i in the unblurred scene
  Calculate d_i, the depth of the object under p_i
  Calculate the radius r_i for the corresponding circle of confusion (CoC)
  $r_i \propto |d_f - d_i| * r_{max}$
  Scale the circular blur kernel M_i by r_i
end for
Create an output image Q consisting of pixels $q_{0..n}$
for Each pixel p_i
  Calculate N_i by multiplying p_i (RGB channel) by M_i
  Blend N_i into Q, centered at q_i
end for
Return Q

Algorithm 1. The blurred scene is generated using a circular bokeh blur kernel.

The second paper "The Effect of Out-of-focus Blur on Visual Discomfort When Using Stereo Displays" is all about approaches and techniques offering good stereoscopic vision that does not lead to simulator sickness, minimizes visual discomfort and at the same time offers a realistic perception of depth. The issues like negative effect of high disparities on the ability to fuse images of stereo displays and also for the human vision. The other major one is the occurrence of double vision (diplopia), when focusing on a far object while putting a finger close to the eye, a double image of the finger will be seen. There are some issues, which are not yet solved completely. The main objective of this paper was to investigate the effect of out-of-focus blur on visual discomfort when using stereo displays. They have experimented the above for both HMD and stereo monitor. The main hypothesis was, that applying blur to no fixated layers in a scene would lead to lower visual discomfort. To do this, three issues have to be addressed. Firstly, the gaze of the user has to be tracked. Secondly, the depth of the gaze point has to be known. The third problem is to blur the image. In order to overcome the issue, they have experimented with few things and they have concluded as there are several ways how such AR system could be built.

They performed an experiment on using artificial depth of field to reduce visual discomfort when using stereo displays. The main hypothesis was that out-of-focus blur would reduce visual discomfort due to double vision. Their results showed a significantly better perceived quality when using out-of-focus blur in virtual scenes. However, for photographed scenes results were not significant. Taking into account that many subjects reported that they did not perceive double vision at all we could not confirm our initial hypothesis without doubt.

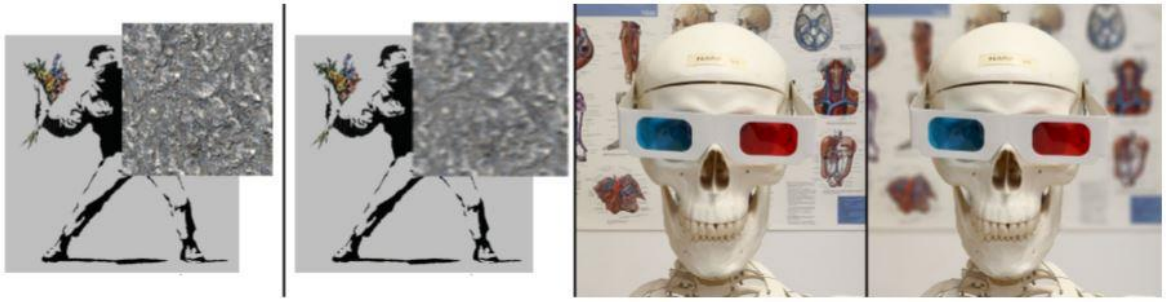

Figure 1: Images with and without simulated out-of-focus blur. On the left a virtual scene is shown, on the right a photographed one.

Reference for paper 1:

T. Blum et al., "The Effect of Out-of-Focus Blur on Visual Discomfort When Using Stereo Displays,"
Proc. 9th IEEE Int'l Symp. Mixed and Augmented Reality (ISMAR), 2010, pp. 13–17.