Phase-Aligned Foveated Rendering for Virtual Reality Headsets

Poster #1152

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Google Daydream

Introduction

Problem Statement

As HMDs become higher-fidelity and wider FOV, aggressive Foveated Rendering is essential. Current techniques produce major flicker artifacts at high foveation levels, limiting their scalability.

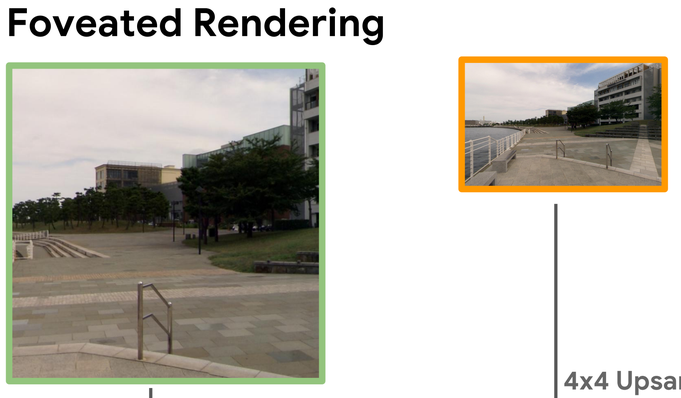
Foveated Rendering

Rendering same scene with fewer pixels in the periphery.

Traditional Rendering

Total # of Pixels: 2.3 Million

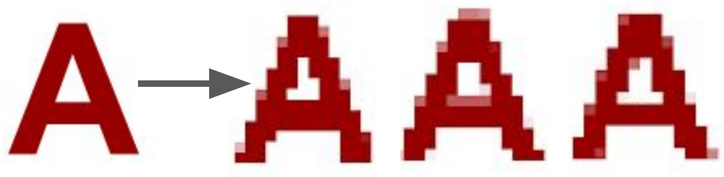
Foveated Rendering



Total # of Pixels: 0.5 Million

Regions overlap via alpha-blending, reducing perceptibility of edge

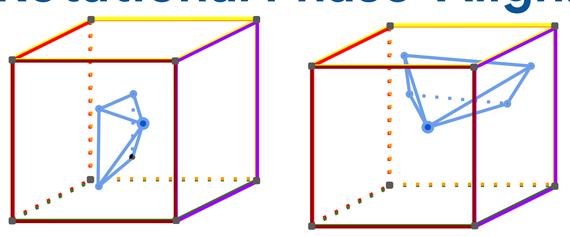
Flickering/Aliasing Artifacts



- Same shape.
- Downsampled the same amount.
- Different artifacts based on pixel phase alignment.
- Head-motion leads to flickering in peripheral proportional to downsample factor.

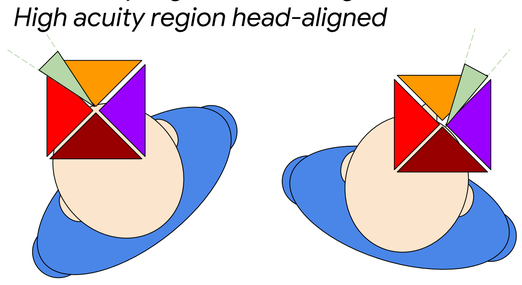
Method

Rotational Phase-Alignment



3D Frustum View

- *Low acuity regions world-aligned faces of cube*
- *High acuity region head-aligned*



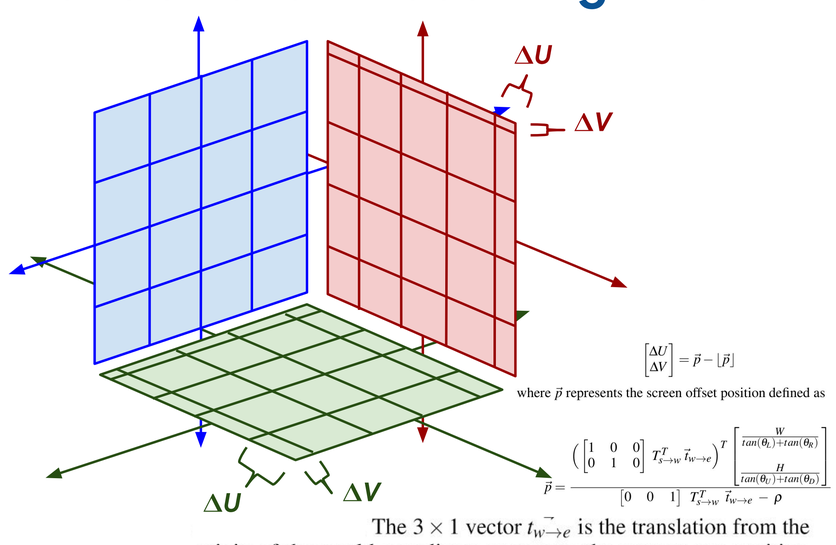
Top View

- *As user rotates, LA regions remain world-aligned.*

Composited Image

- *3 LA, 1 HA rendered*
- *Upsampling and compositing done in world-space*

Translational Phase-Alignment



$$\begin{bmatrix}\Delta U\\ \Delta V\end{bmatrix} = \vec{p} - \lfloor \vec{p} \rfloor$$

where $\vec{p}$ represents the screen offset position defined as

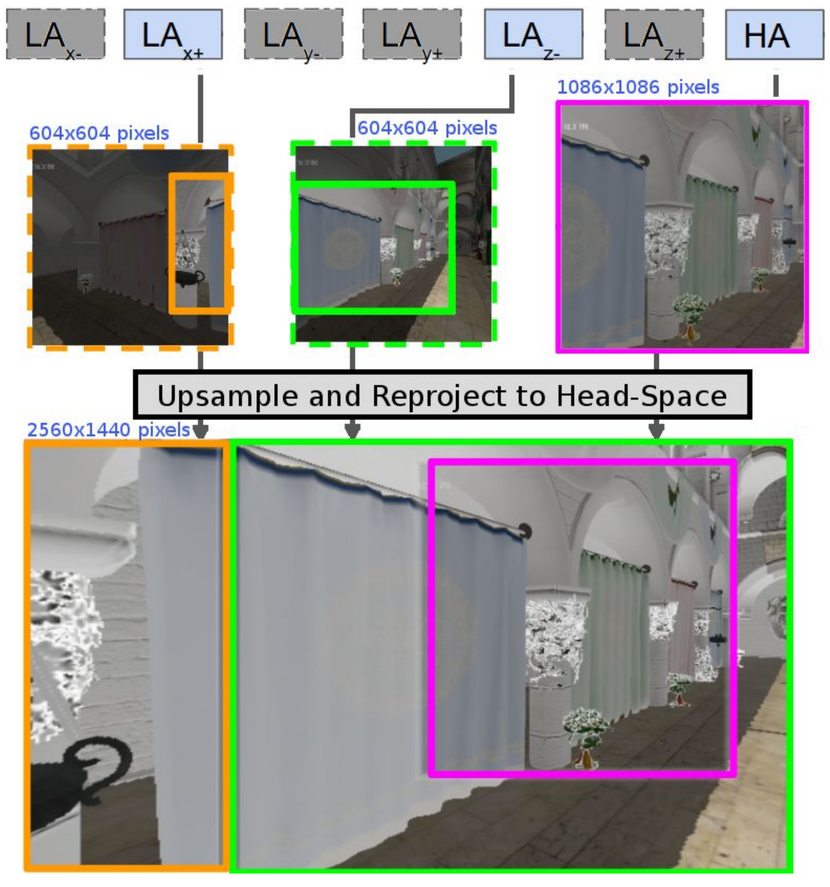
$$\vec{p} = \frac{\left(\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\end{bmatrix} T^{T}_{s\to w}\, \vec{t}_{w\to e}\right)^{T} \begin{bmatrix}\frac{W}{t\tan(\theta_L)+t\tan(\theta_R)}\\ \frac{H}{t\tan(\theta_U)+t\tan(\theta_D)}\end{bmatrix}}{\begin{bmatrix}0 & 0 & 1\end{bmatrix} T^{T}_{s\to w}\, \vec{t}_{w\to e} - \rho}$$

The 3×1 vector $\vec{t_{w\to e}}$ is the translation from the origin of the world coordinate system to the current eye position.

$T_{e\to w}$ is the 4×4 homomorphic transform matrix

ρ indicates an assumed uniform depth of the scene content

Region Selection and Culling

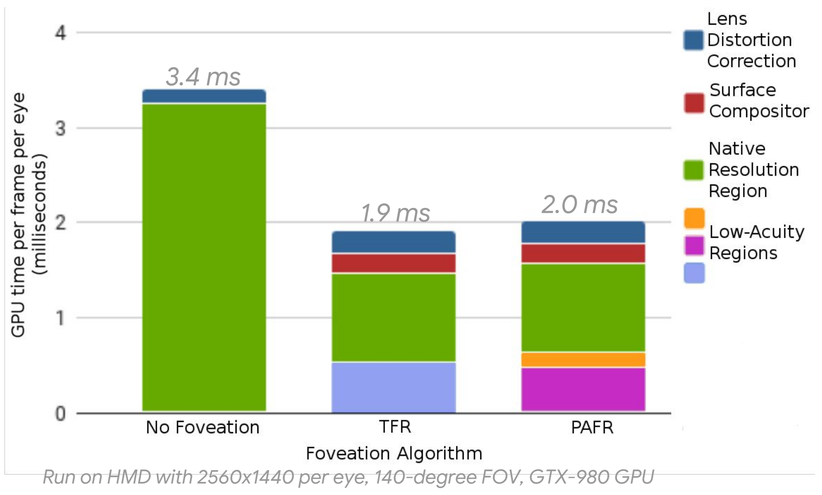


- *Subset of low acuity regions selected for current frame*
- *Only portion of framebuffer overlapping with output display is rendered to. Remainder is masked via depth-culling.*
- *Selected regions composited to final frame, sent for lens distortion.*
- *1.5M pixels instead of 3.7M.*

Results

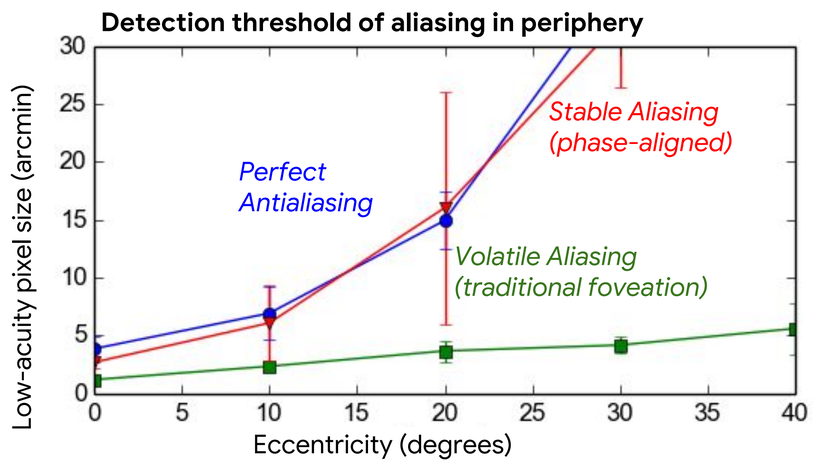
Computational Savings Analysis

Phase-alignment adds slight overhead, but allows for more aggressive foveation, leading to net savings.



Run on HMD with 2560x1440 per eye, 140-degree FOV, GTX-980 GPU

Perception of Aliasing



Study taken from [4]. By performing phase-alignment, more aggressive foveation can be applied to achieve the same visual quality.

User Preference Analysis

We asked users to rate preference between traditional foveation and phase-aligned foveation with increasing foveation aggressiveness in periphery.

At foveation levels where both types of aliasing are detectable, users rate PAFR as superior.

[4] D. M. Hoffman, Z. Meraz, and E. Turner. Sensitivity to peripheral artifacts in vr display systems. to appear in SID Symposium Digest Technical Paper, 2018.