A Log-Rectilinear Transformation for Foveated 360-Degree Video Streaming

David Li[†], Ruofei Du[‡], Adharsh Babu[†], Camelia Brumar[†], Amitabh Varshney[†]

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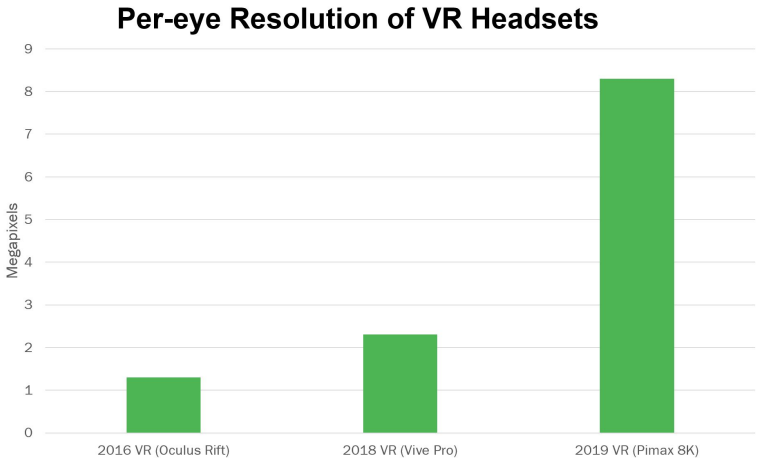
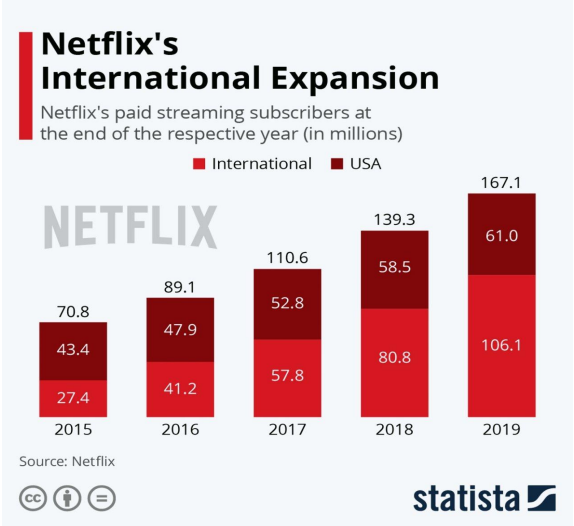
Outline

- Background on 360° Video Streaming and Log-Polar Foveation
- Summed Area Tables and Log-Rectilinear Transformation
- Foveated Streaming Pipeline
- Qualitative and Quantitative Results

Current Landscape

- 360 Cameras and VR headsets are increasing in resolution.
- Video streaming is quickly increasing in popularity.





Current Landscape

- Commercial VR headsets are getting eye-tracking capabilities.

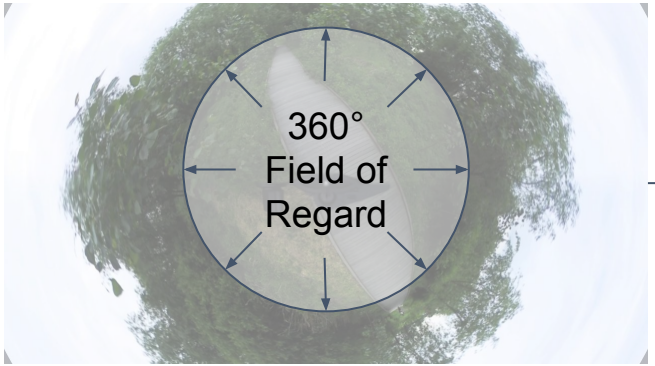
HTC Vive Eye

Varjo VR-3

Fove

360° Videos

- 360 cameras capture the scene in every direction with a full 360 degree spherical field of regard.
- These videos are typically stored in the equirectangular projection parameterized by spherical coordinates (θ, φ).



Scene

Captured 360 Video

360° Videos

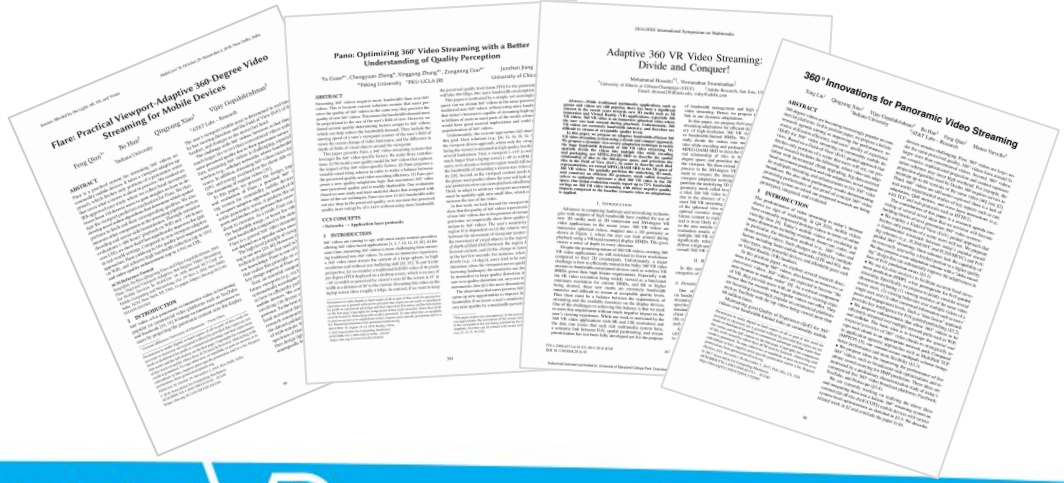
- When viewed in a VR headset, 360° videos cover the entire field-of-view for more immersive experiences.
- However, transmitting the full field-of-regard either has worse perceived quality or requires far more bandwidth than for conventional videos.

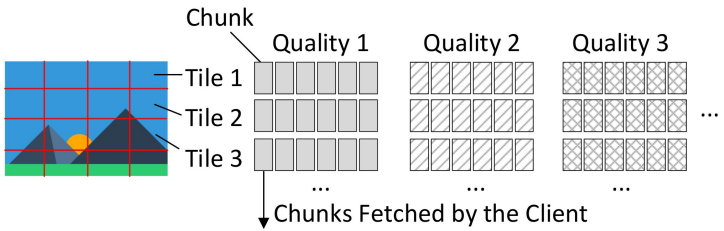
Captured 360 Video

Projection to Field of View

Viewport Dependent 360° Video Streaming

- Existing work in 360° streaming focuses on viewport dependent streaming by using tiling to transmit only visible regions based on the user's head rotation.

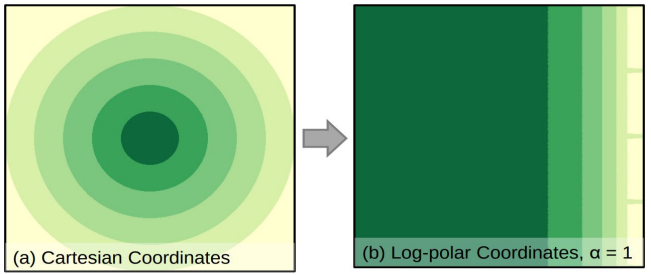




Tiling Illustration
Image from (Liu *et al.*, 2017)

Foveated Rendering

- Foveated rendering renders the fovea region of the viewport at a high-resolution and the peripheral region at a lower resolution.
- Kernel Foveated Rendering (Meng *et al.,* PACMCGIT 2018) uses a log-polar transformation to render foveated images in real-time.



Log-polar Transformation,
Image from (Meng *et al.*, 2018)

Log-Polar Foveated Streaming

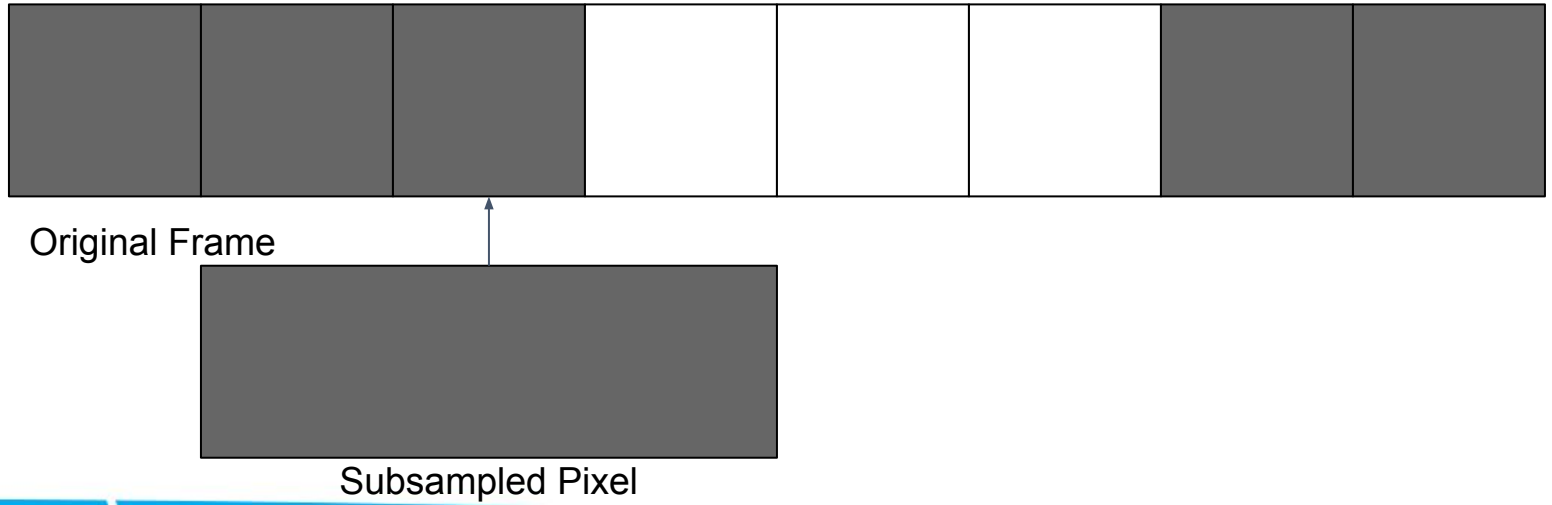
- Applying log-polar subsampling to videos results in flickering and aliasing artifacts in the foveated video.

Research Questions

- Can foveation techniques from rendering be used to optimize 360 video streaming?
- How can we reduce foveation artifacts by leveraging the full original video frame?

Log-Polar Foveated Streaming

- Artifacts are caused by subsampling of the original video frame.



Log-Polar Foveated Streaming

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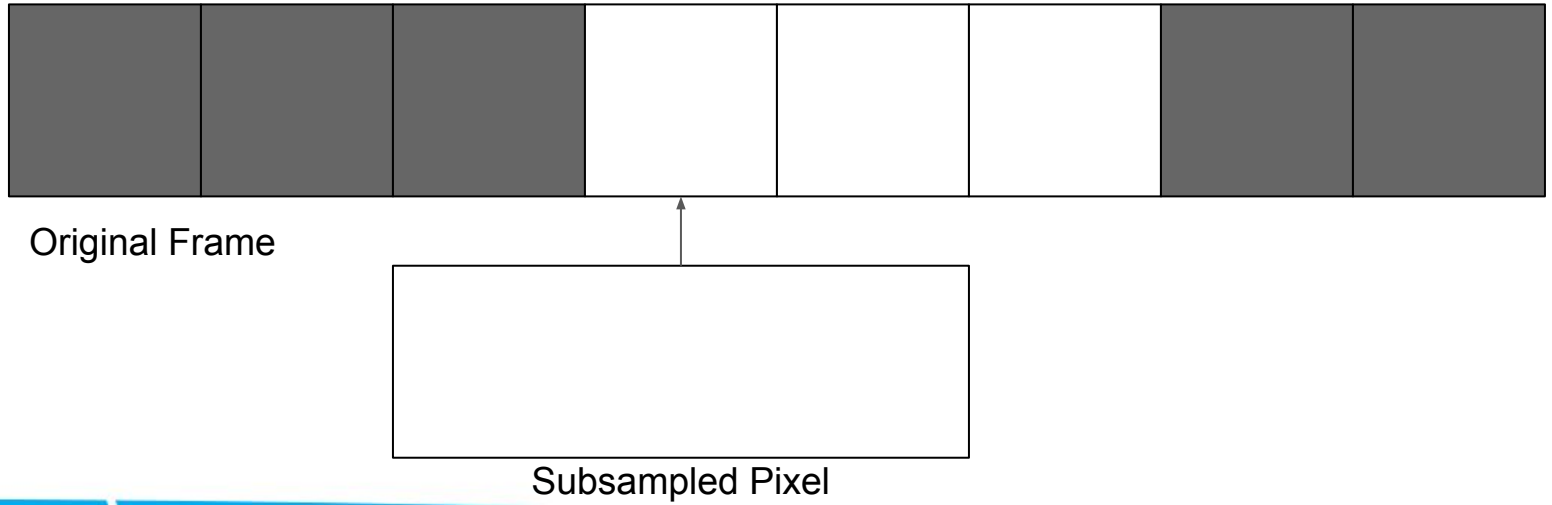
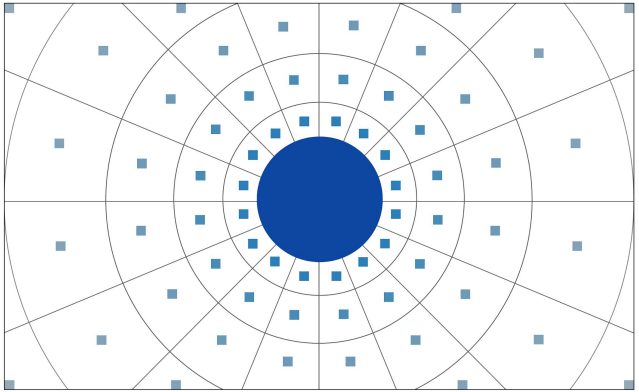


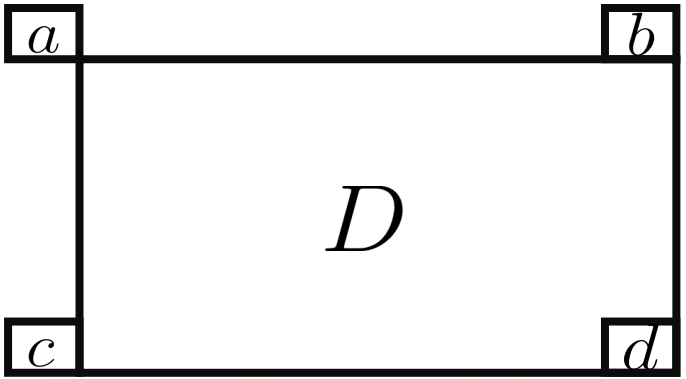
Log-Polar Foveated Streaming

- Subsampled pixels should represent an average over an entire region of the original video frame.
- Computationally, this would take O(region size) time to compute for each sample.



Summed-Area Tables

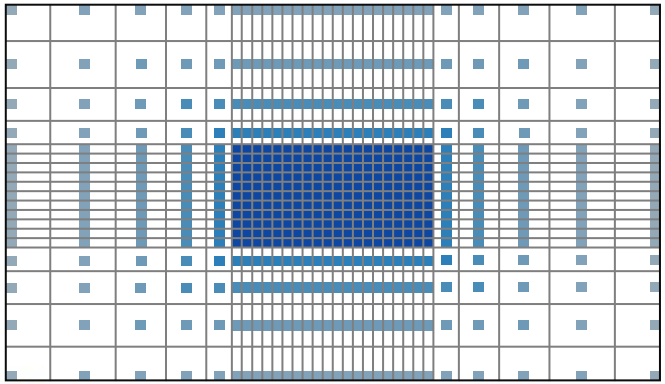
- One way to compute averages quickly is using summed-area tables, also known as integral images.
- Sampling a summed area table only takes O(1) time.



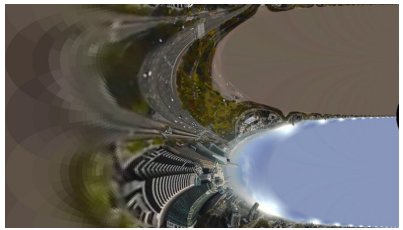
$$\mathrm{Sum}(D) = a - b - c + d$$

Log-Rectilinear Transformation

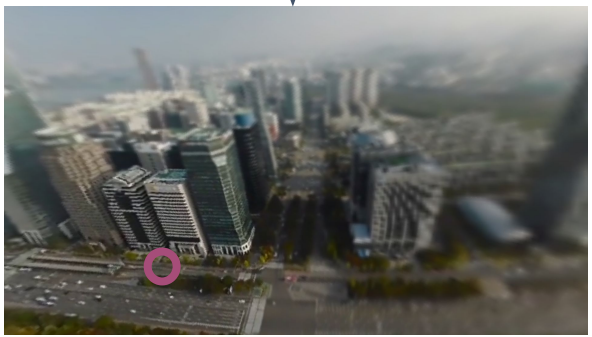
- Apply exponential drop off along x-axis and y-axis independently.
- Rectangular regions allow the use of summed area tables for subsampling.
- A one-to-one mapping near the focus region preserves the resolution of the original frame.

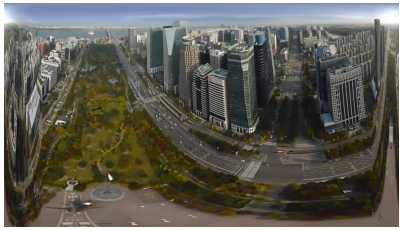


Log-Polar vs Log-Rectilinear

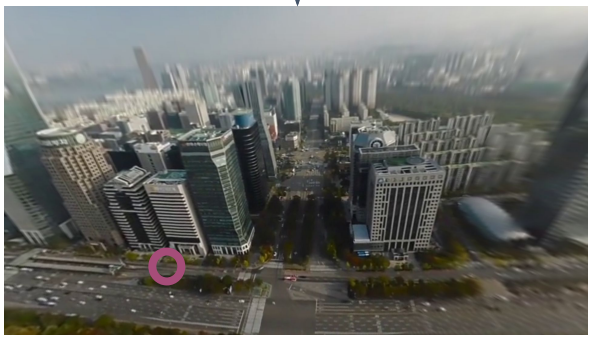


log-polar buffer

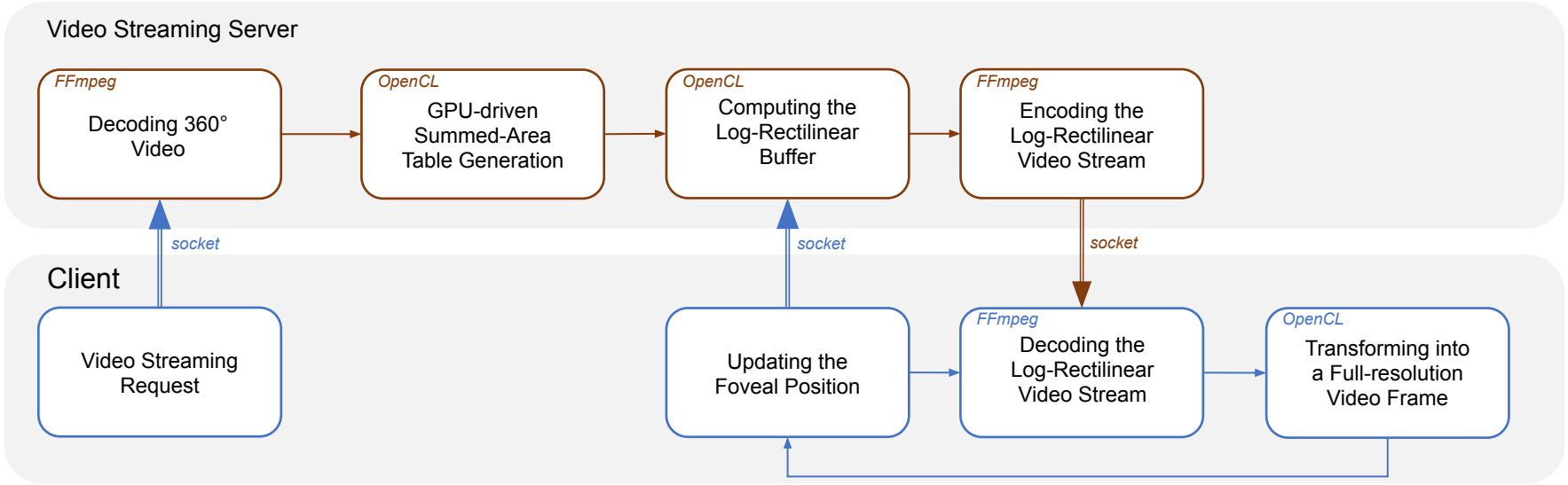




log-rectilinear buffer



Foveated Streaming Pipeline



Qualitative Results

- Shown with gaze at the center of the viewport

Quantitative Results

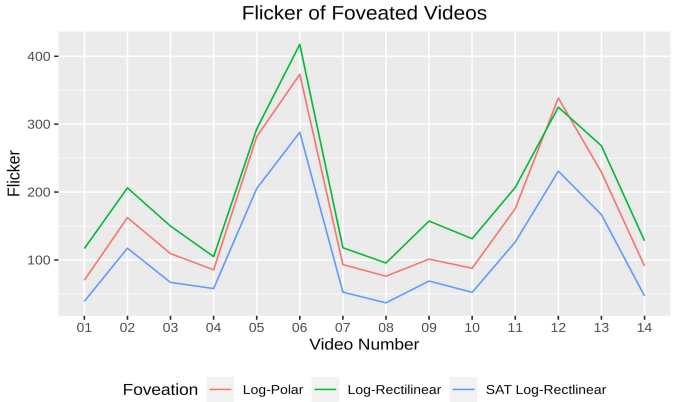
We perform quantitative evaluations comparing the log-rectilinear transformation and the log-polar transformation in 360° video streaming.

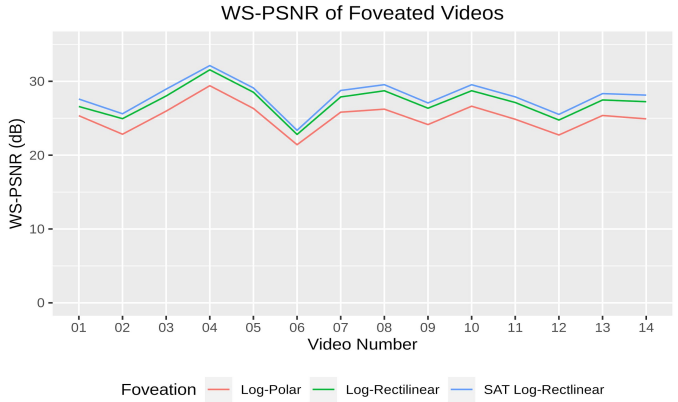
- Performance overhead of summed-area tables.
- Full-frame quality.
- Bandwidth usage.

Sampling Method	Decoding (ms)	Processing (ms)	Sampling (ms)	Encoding (ms)	Total (ms)
Log-Polar	6.14	1.91	0.55	2.86	11.46
Log-Rectilinear	6.13	1.91	0.53	2.85	11.43
SAT Log-Rectilinear	6.14	3.00	0.46	2.84	12.44

Quantitative Results

- Pairing the log-rectilinear transformation with summed area table filtering yields lower flickering while also reducing bandwidth usage and returning high weighted-to-spherical signal to noise ratio (WS-PSNR) results.





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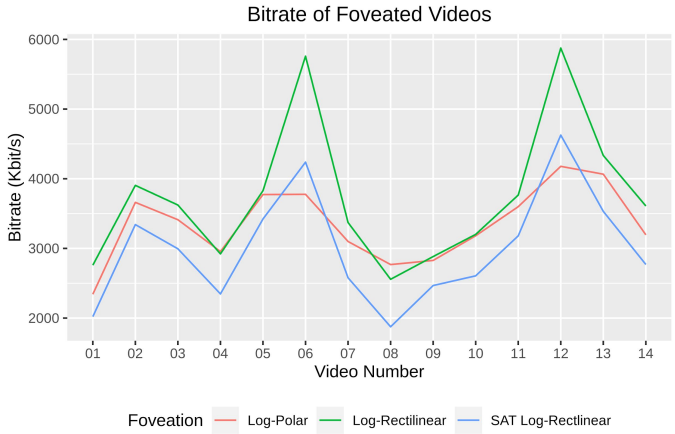

Conclusion

- We present a log-rectilinear transformation which utilizes foveation, summed-area tables, and standard video codecs for foveated 360° video streaming.