60 MS TO GET IT RIGHT

GAZE-CONTINGENT RENDERING & HUMAN PERCEPTION

Dr. Rachel Albert, GTC San Jose 2019

GOAL: IMMERSIVE VR

Requirements to mimic real-world human visual experience

- Wide color gamut / high dynamic range
- High frame rate, Low latency
- Wide Field of View (FoV)
- High spatial resolution

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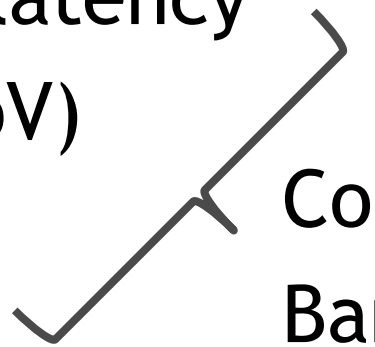


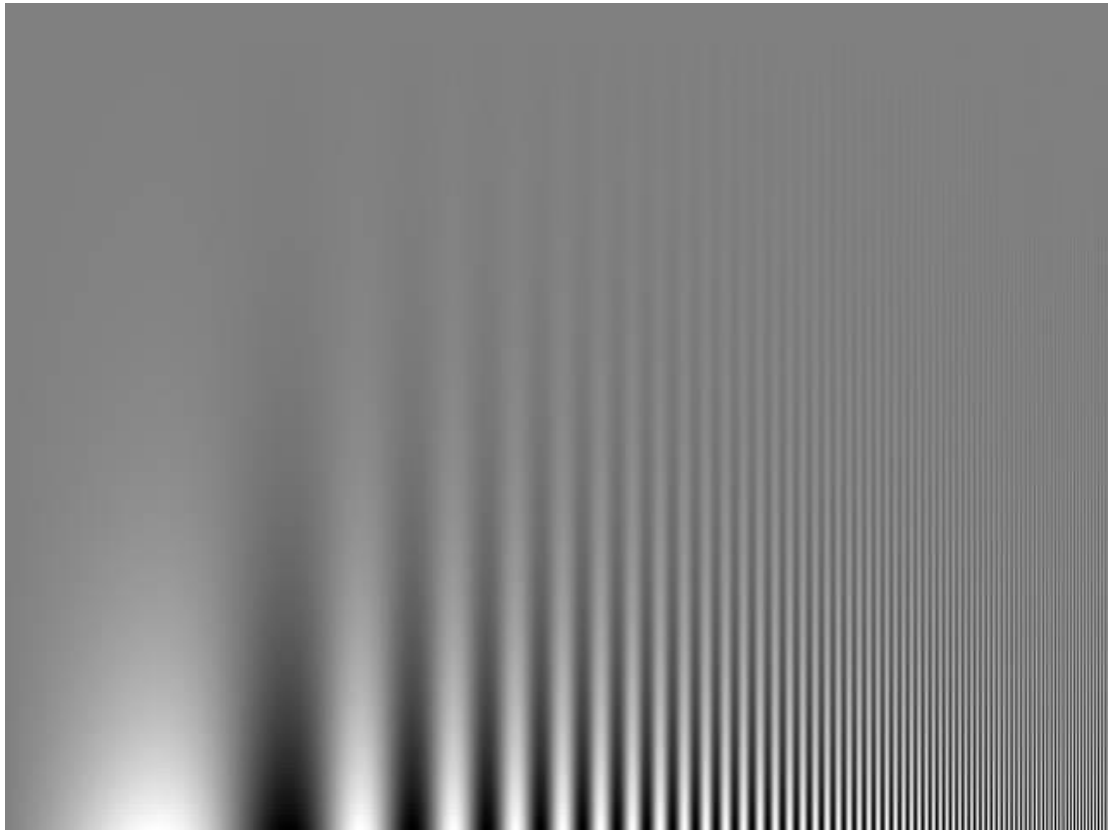
Computation Cost

Bandwidth

Power/Heat/Weight

HUMAN VISUAL PERCEPTION IS LIMITED

Detection Threshold



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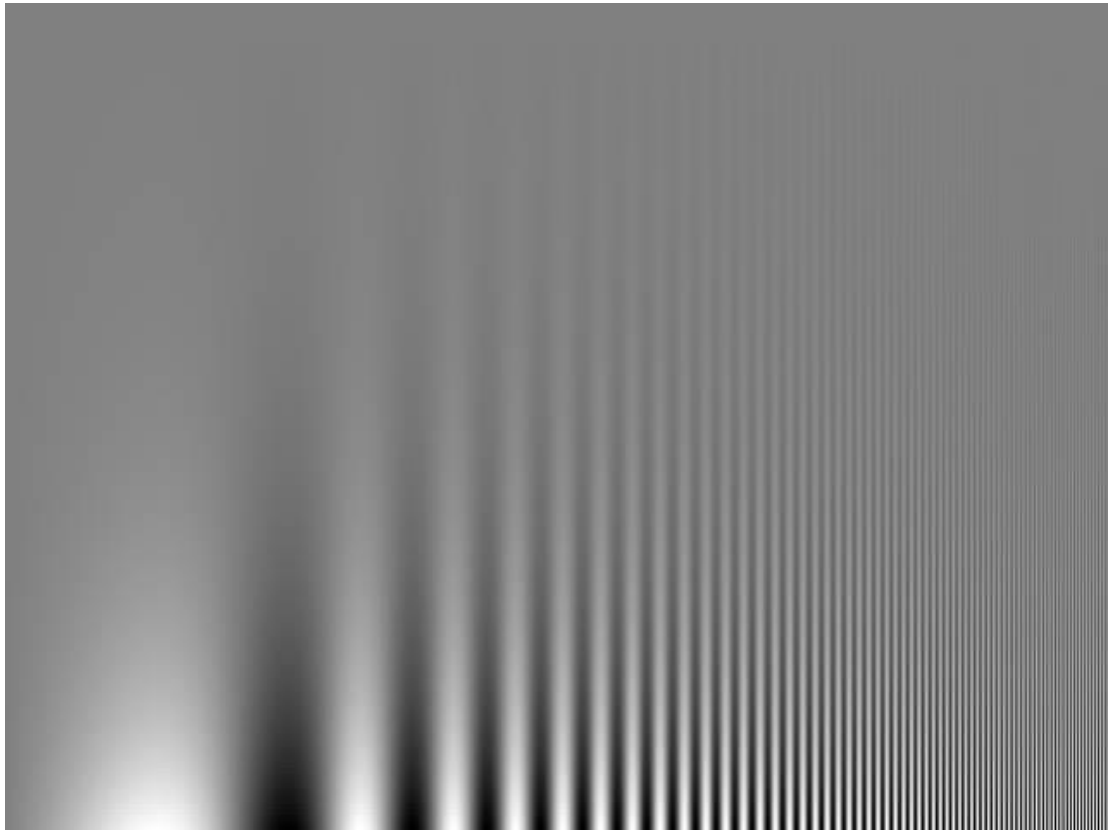
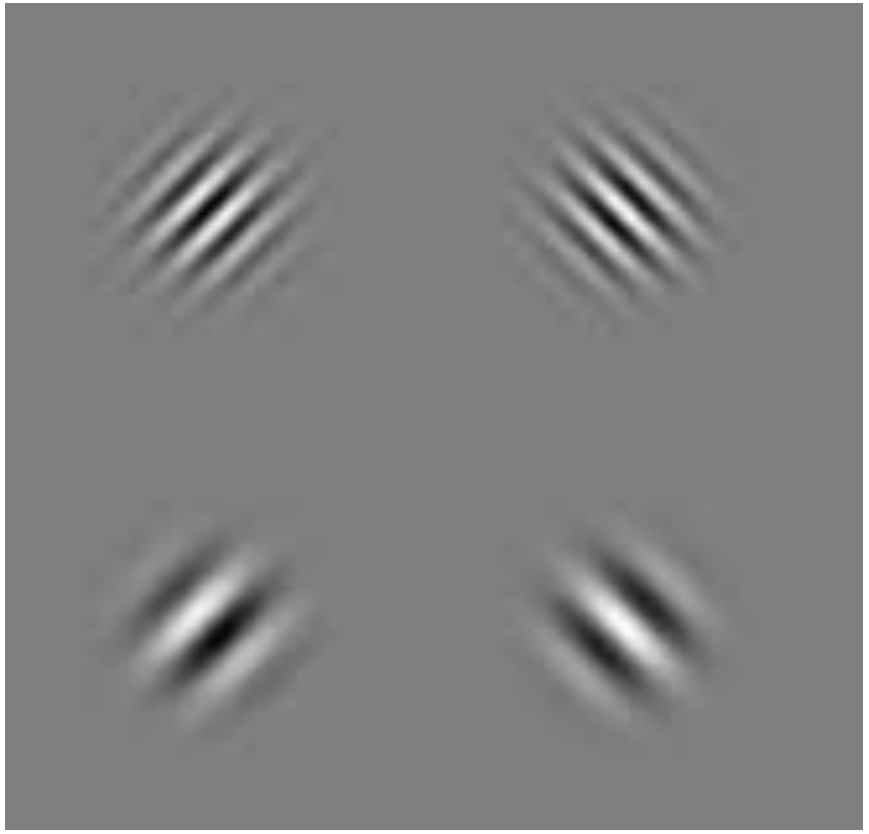


Resolution Threshold

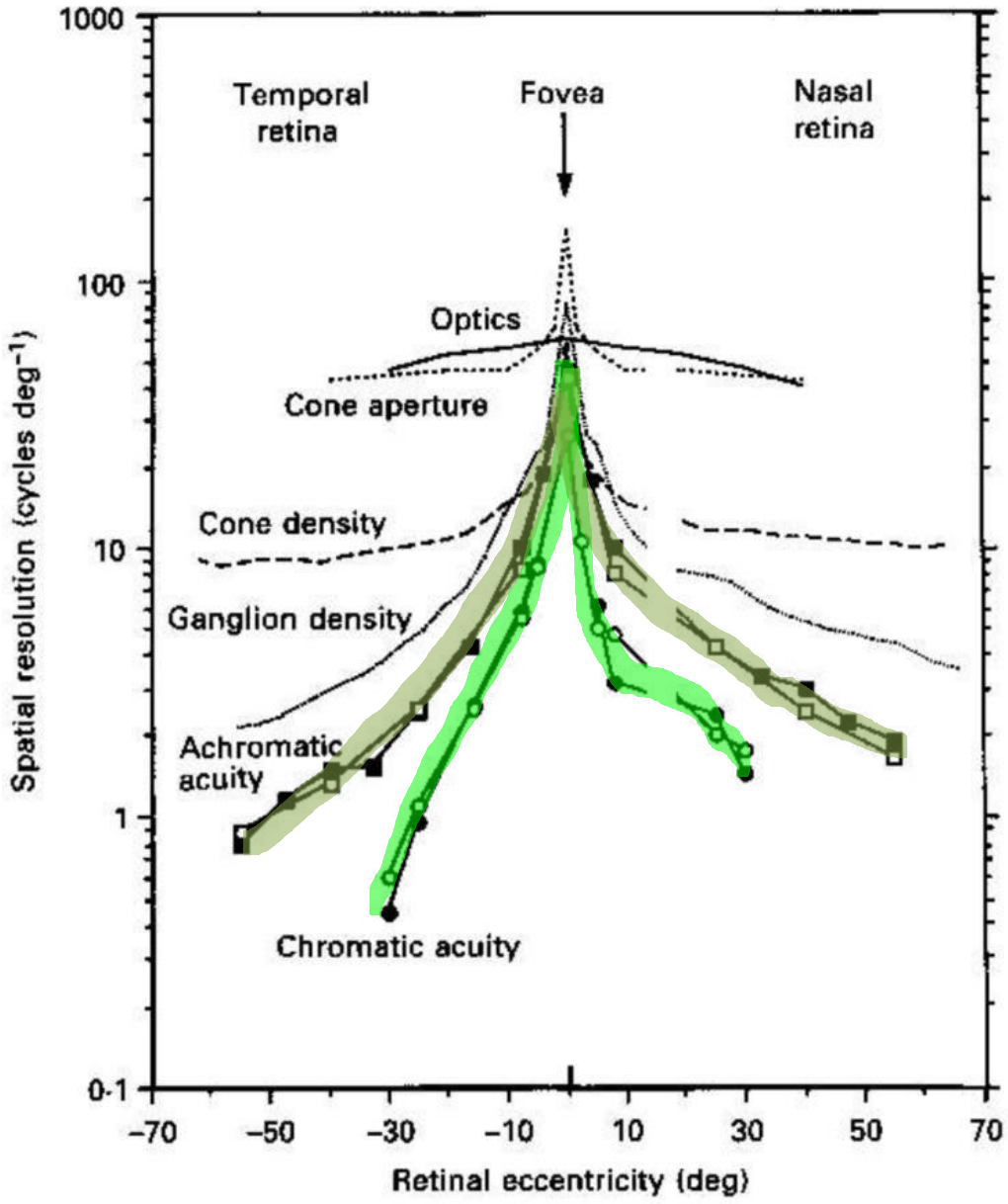


HUMAN VISUAL PERCEPTION IS NON-UNIFORM

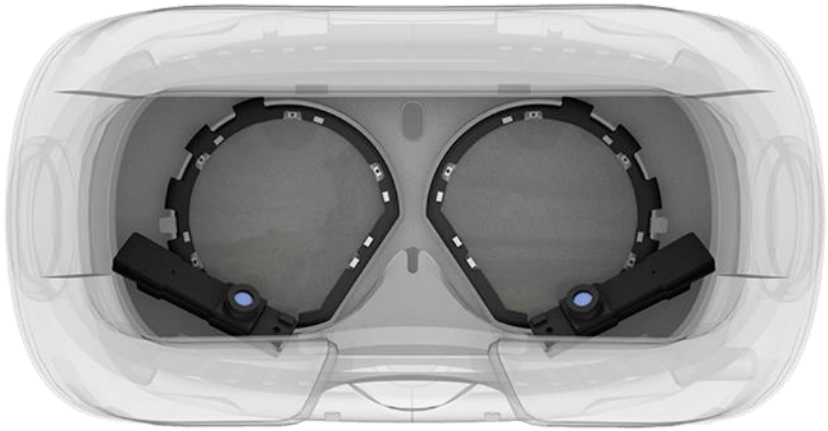
Resolvable spatial resolution decreases in the periphery as a function of eccentricity.

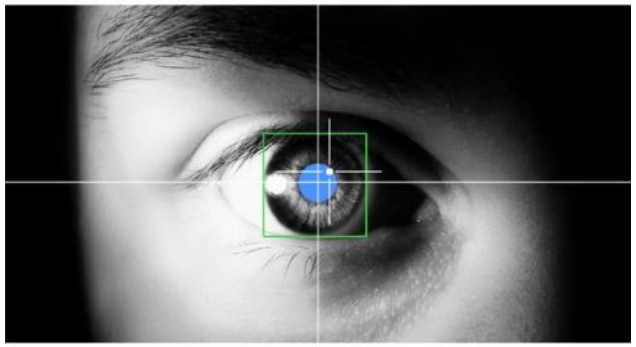
Figure from Anderson et al. 1991

- Achromatic Acuity
- Chromatic Acuity

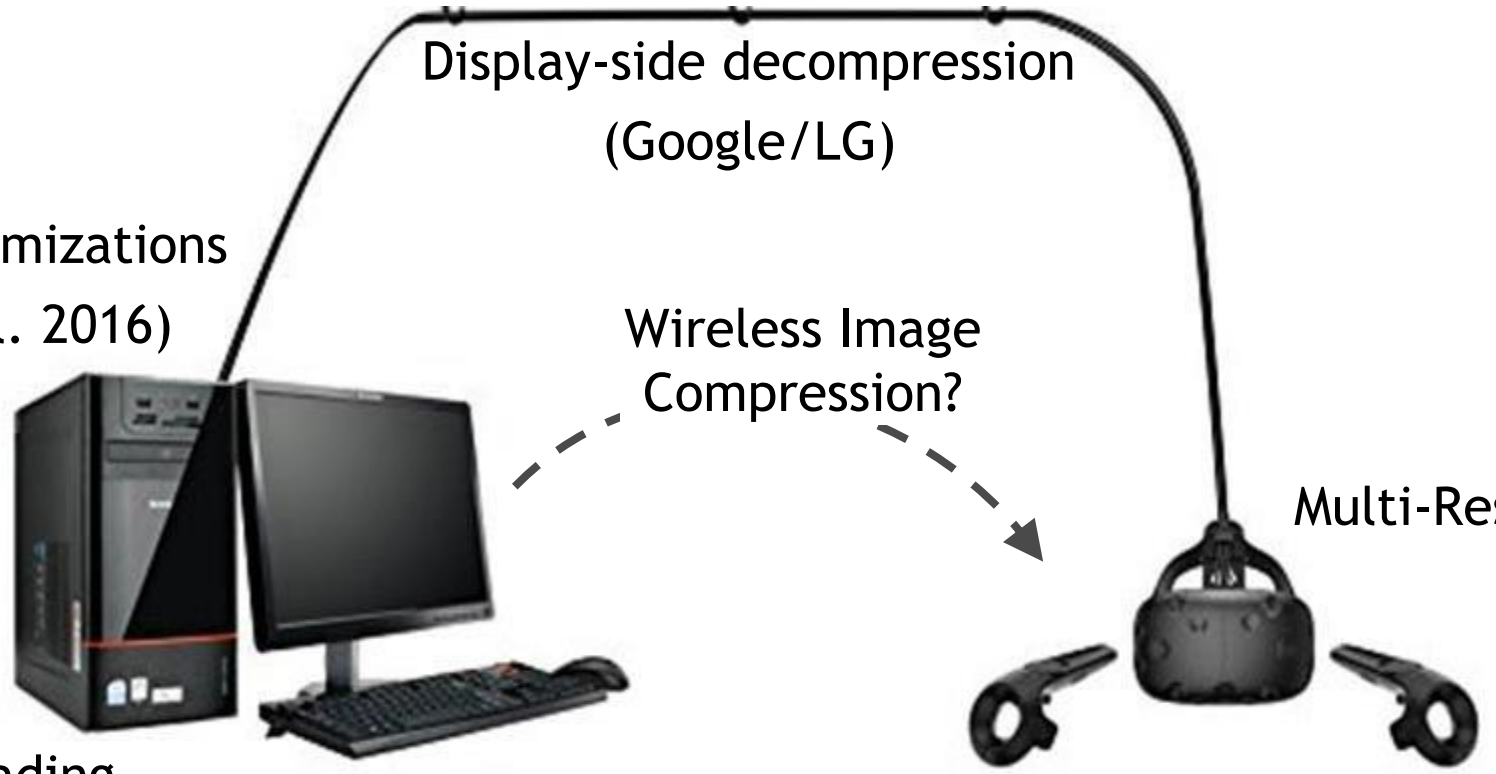


ONE SOLUTION: GAZE-CONTINGENT IMAGERY





SYSTEM REQUIREMENTS FOR GAZE-CONTINGENT RENDERING



SACCADIC EYE MOVEMENTS & SACCADIC OMISSION

- During a saccade, the eye moves at 500 deg/sec
- Latency may cause the peripheral image to be visible
- BUT, Saccadic omission blocks perception of this image

How long is the omission period for rendered scenes?

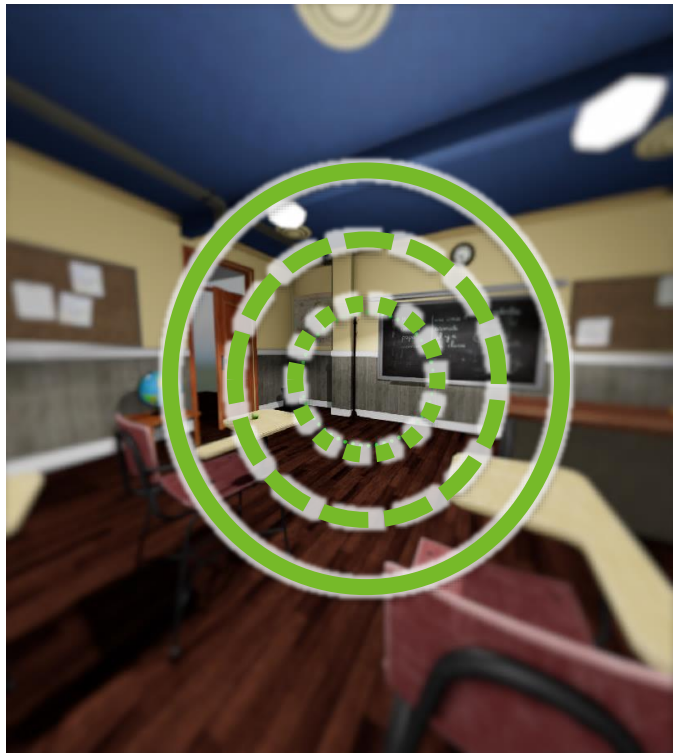
EXPERIMENT: LATENCY REQUIREMENTS FOR GAZE-CONTINGENT RENDERING

- Eye tracking latency only
- Free viewing, 4 seconds per trial
- Task: Yes/No Response
  “Did you see any artifacts?”
- Amount of peripheral degradation varied based on response
  1 up/ 1 down adaptive staircase

EXPERIMENTAL DESIGN

Fovea Size

Full-Resolution Area
5°, 10°, 20° Ecc.



Foveation Technique

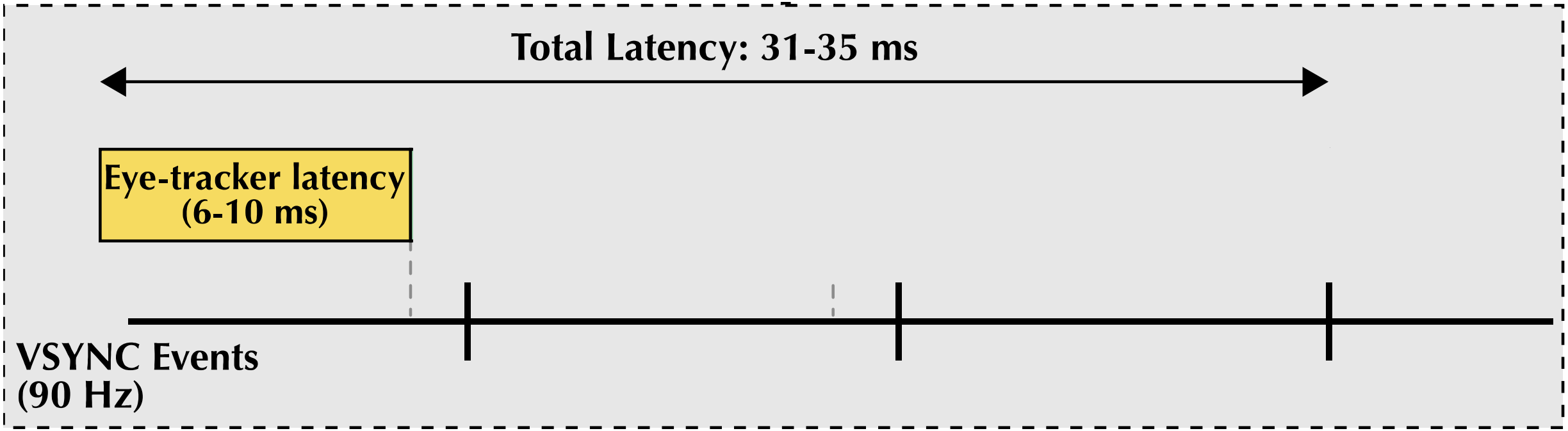
Peripheral Rendering Method
Subsampling, Gaussian, fCPS

Eye-Tracking Latency

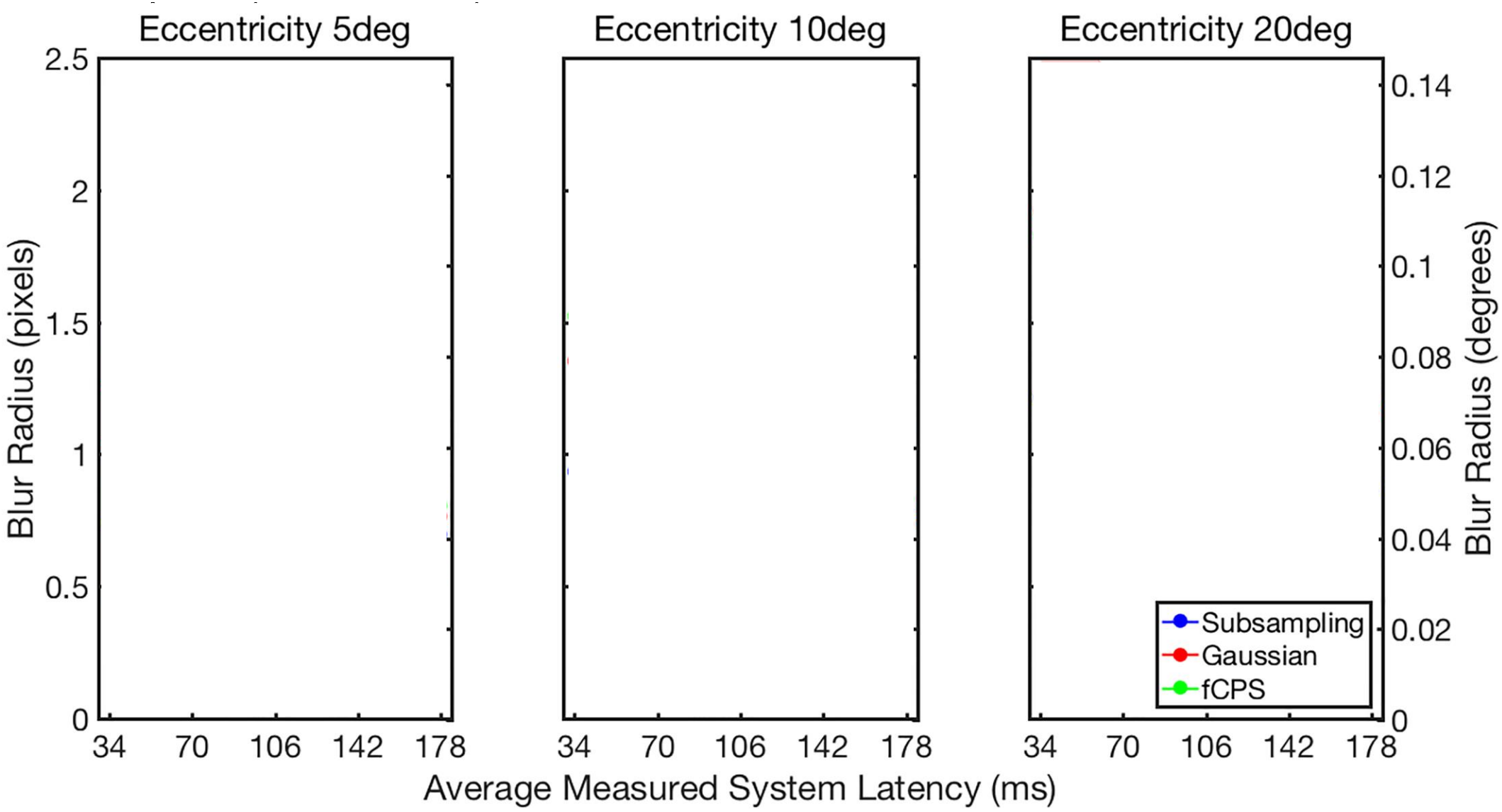
Added Latency
0, 10, 20, 40, 80, 150 ms

“MOTION TO PHOTON”
SACCADE START TO SCREEN UPDATE

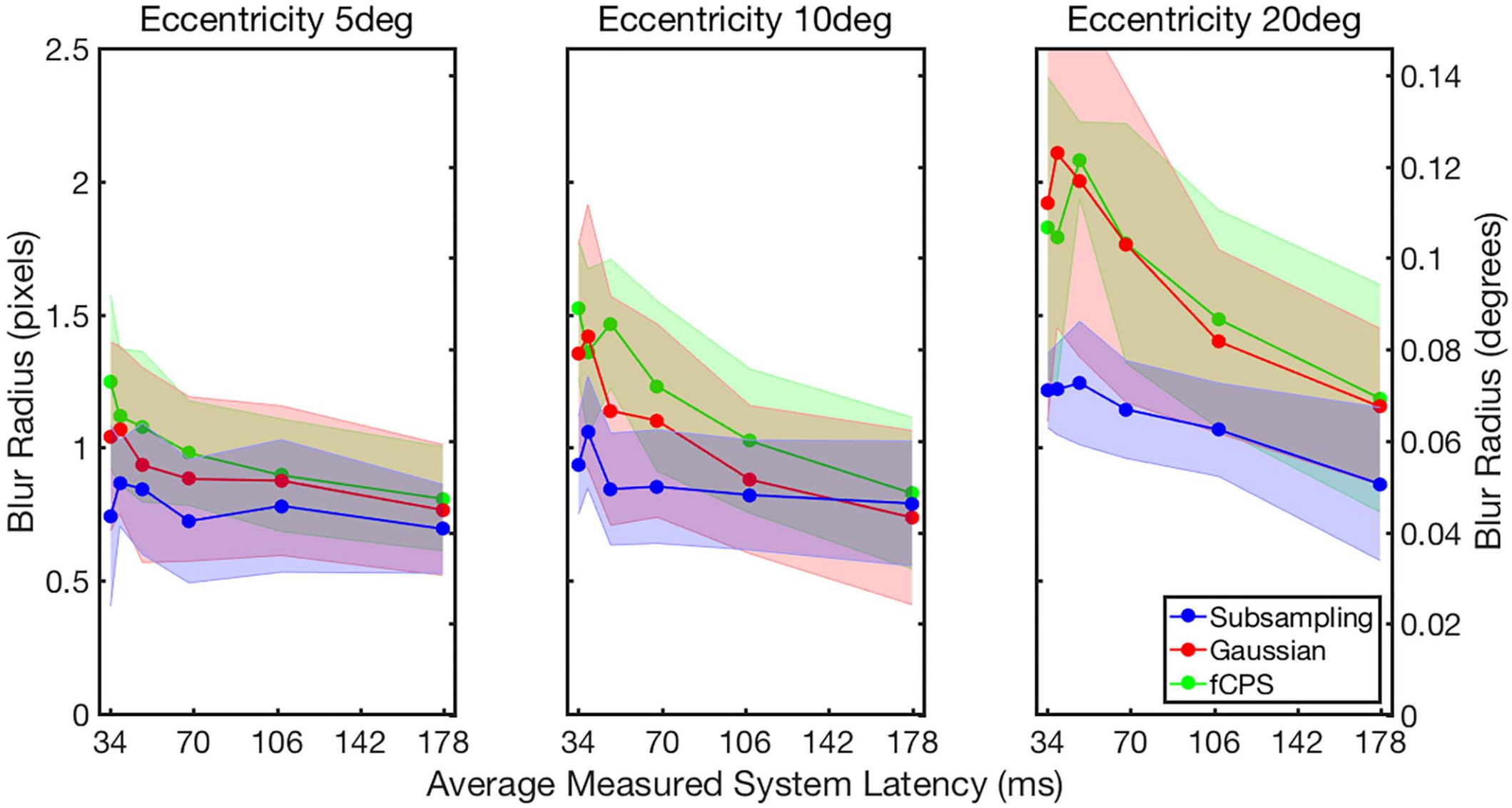
- HTC Vive + SMI Eye Tracker
- NVIDIA Titan X (Pascal) GPU + Falcor rendering framework



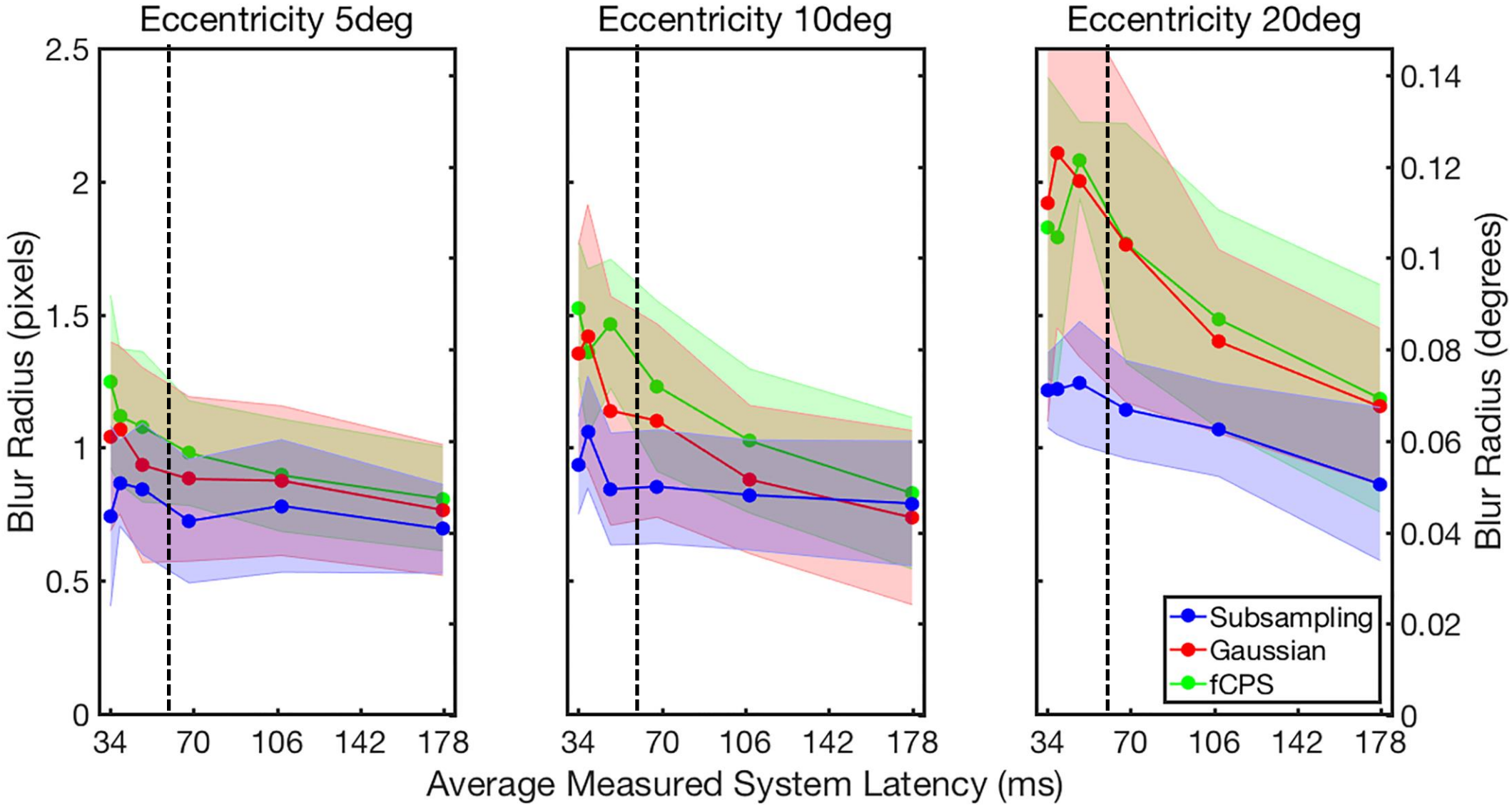
RESULTS


Eccentricity 5deg
Eccentricity 10deg
Eccentricity 20deg
Blur Radius (pixels)
Blur Radius (degrees)
2.5
2
1.5
1
0.5
0
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
34
70
106
142
178
Subsampling
Gaussian
fCPS
Average Measured System Latency (ms)

INTERACTION BETWEEN TECHNIQUE & ECCENTRICITY



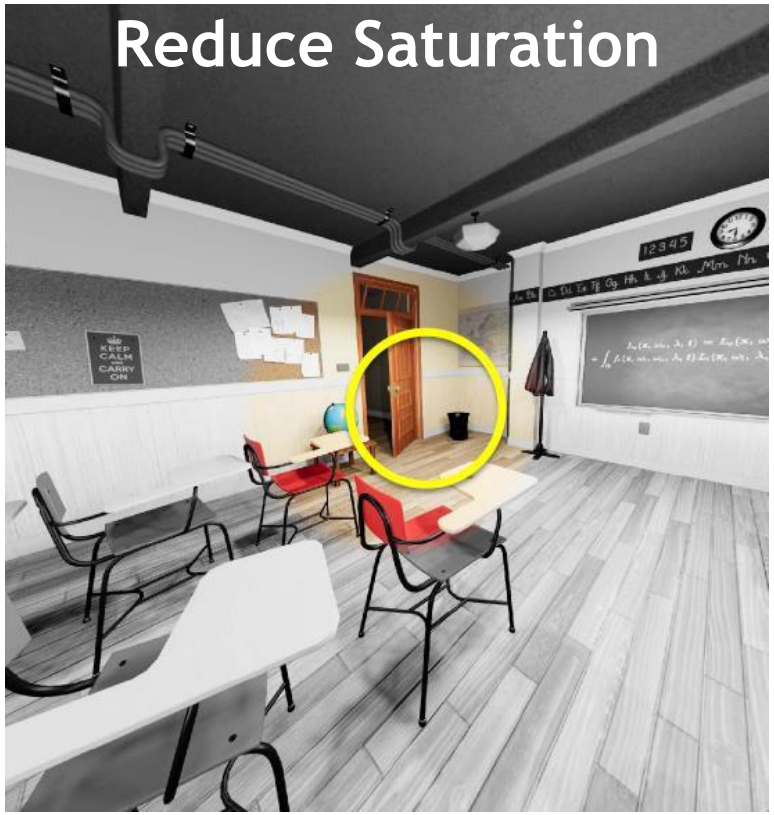
MAIN EFFECT OF LATENCY (THRESHOLD AT 50-70 MS)

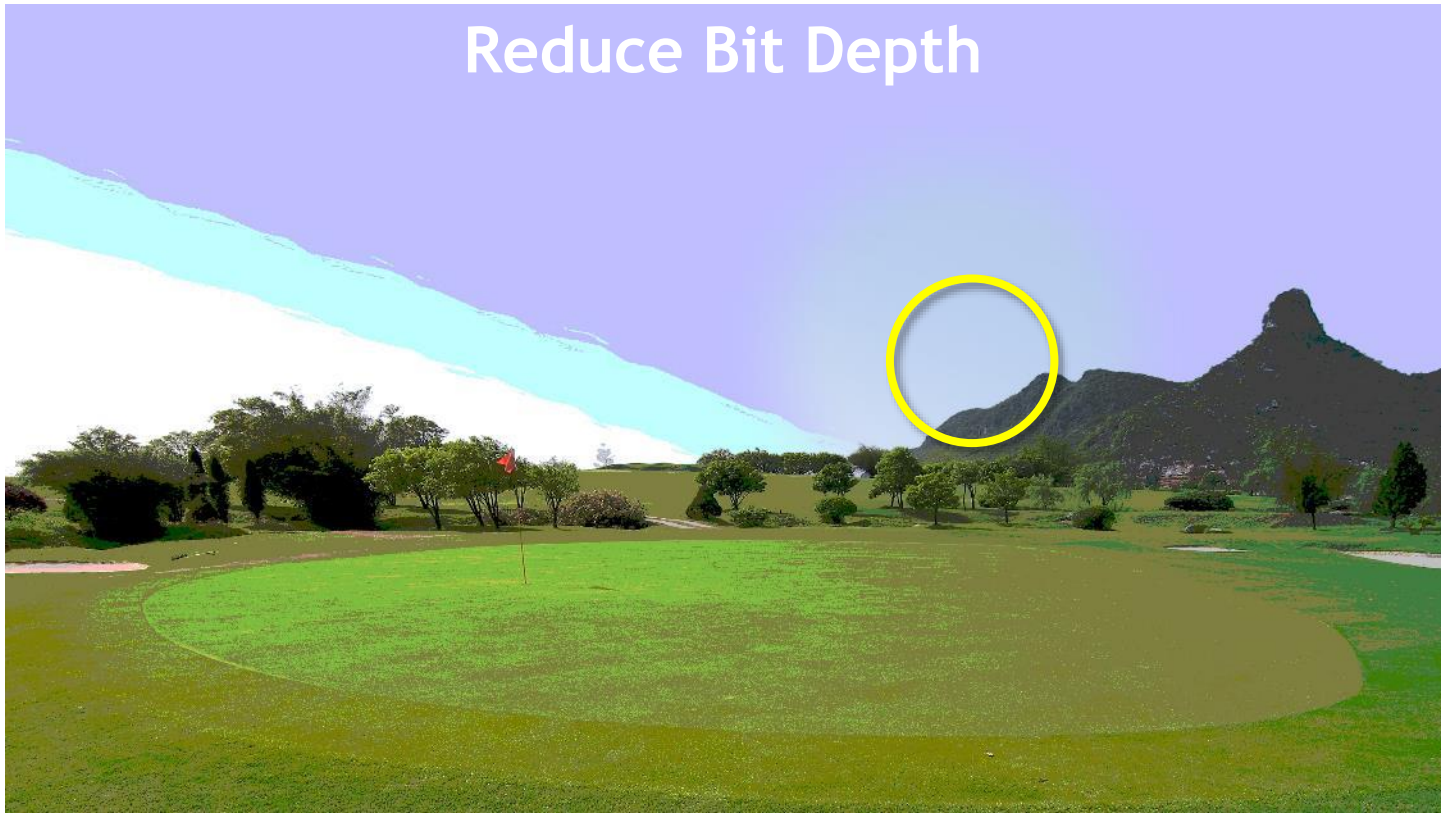


LATENCY EXPERIMENT TAKEAWAY POINTS

- Temporally stable foveation methods support more foveation at larger eccentricities
- All foveation methods and eccentricities show significantly worse performance above 50-70 ms latency

PERIPHERALLY DEGRADING IMAGES WITH COLOR





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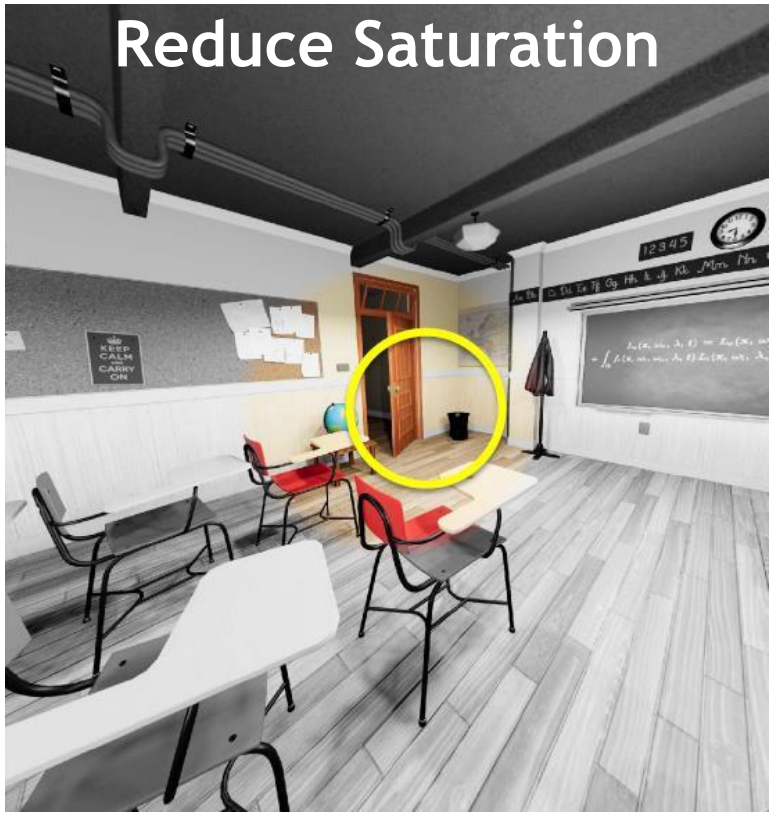
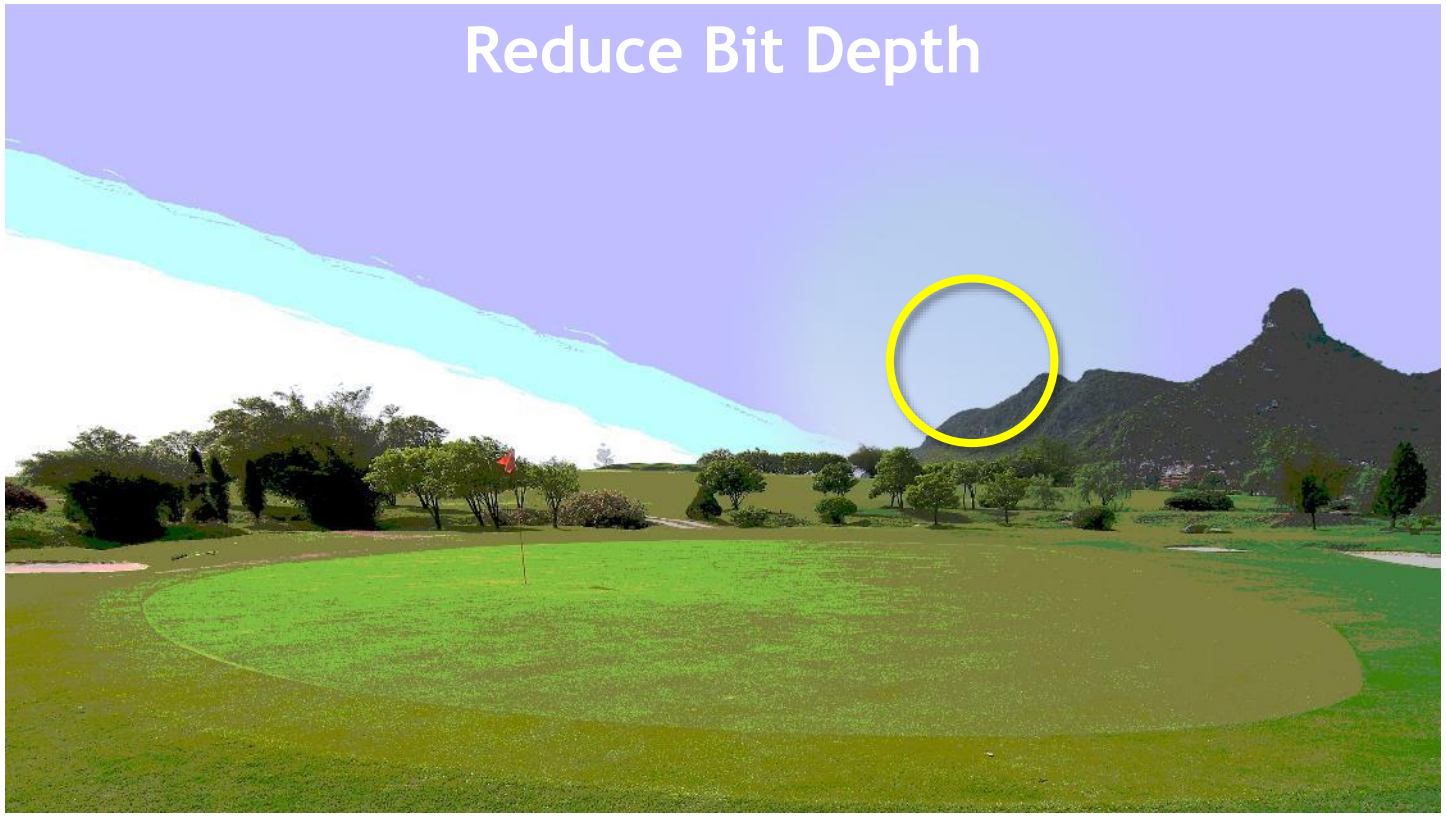
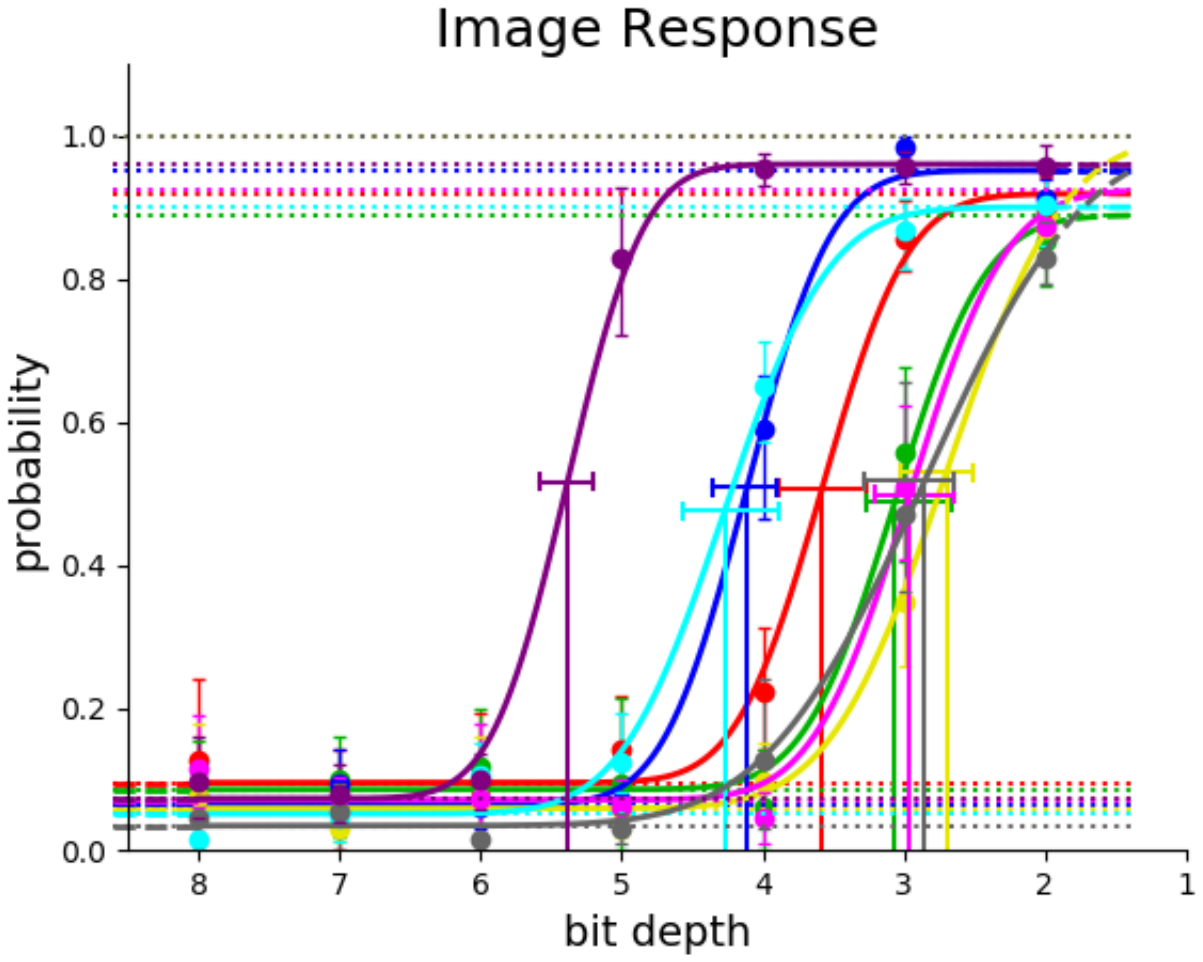
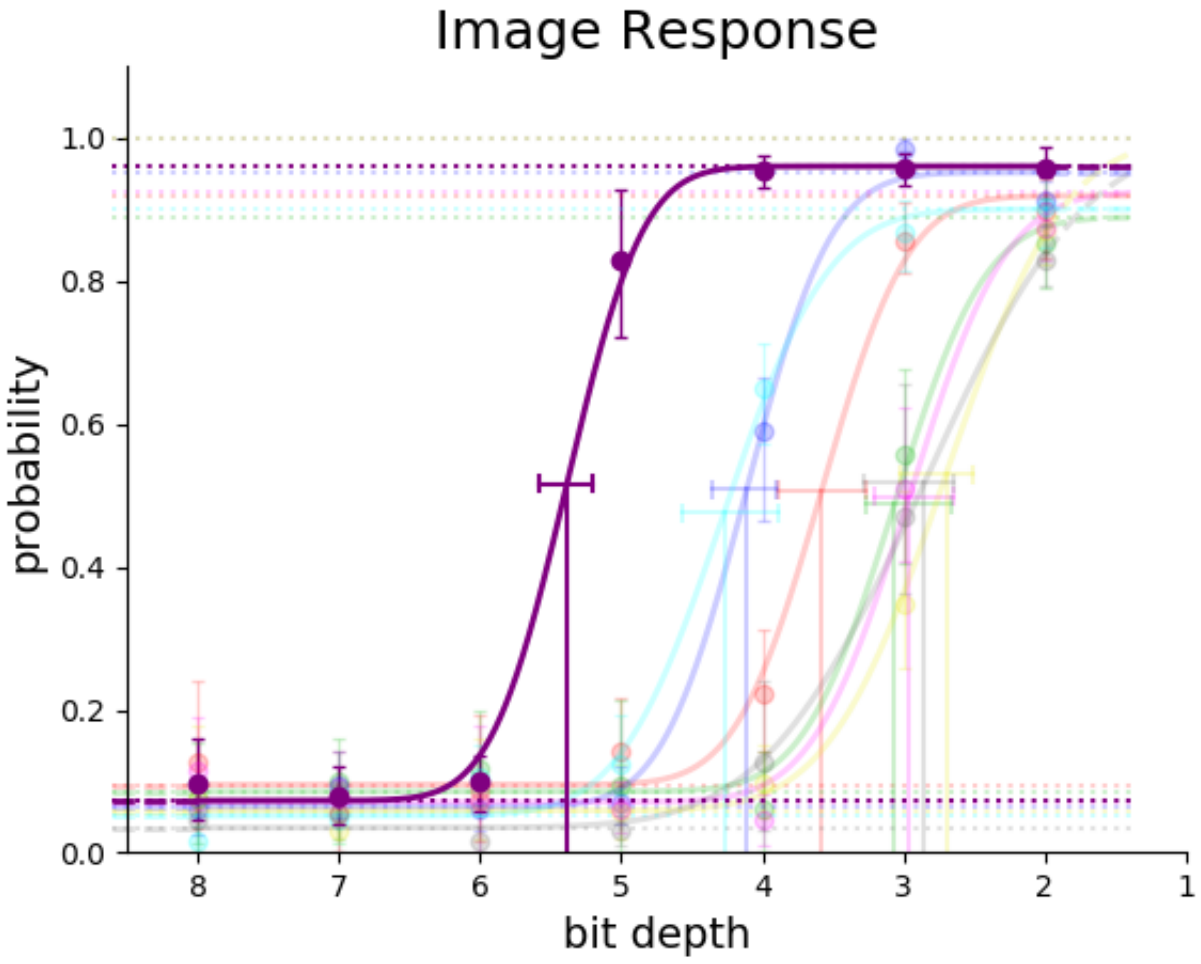




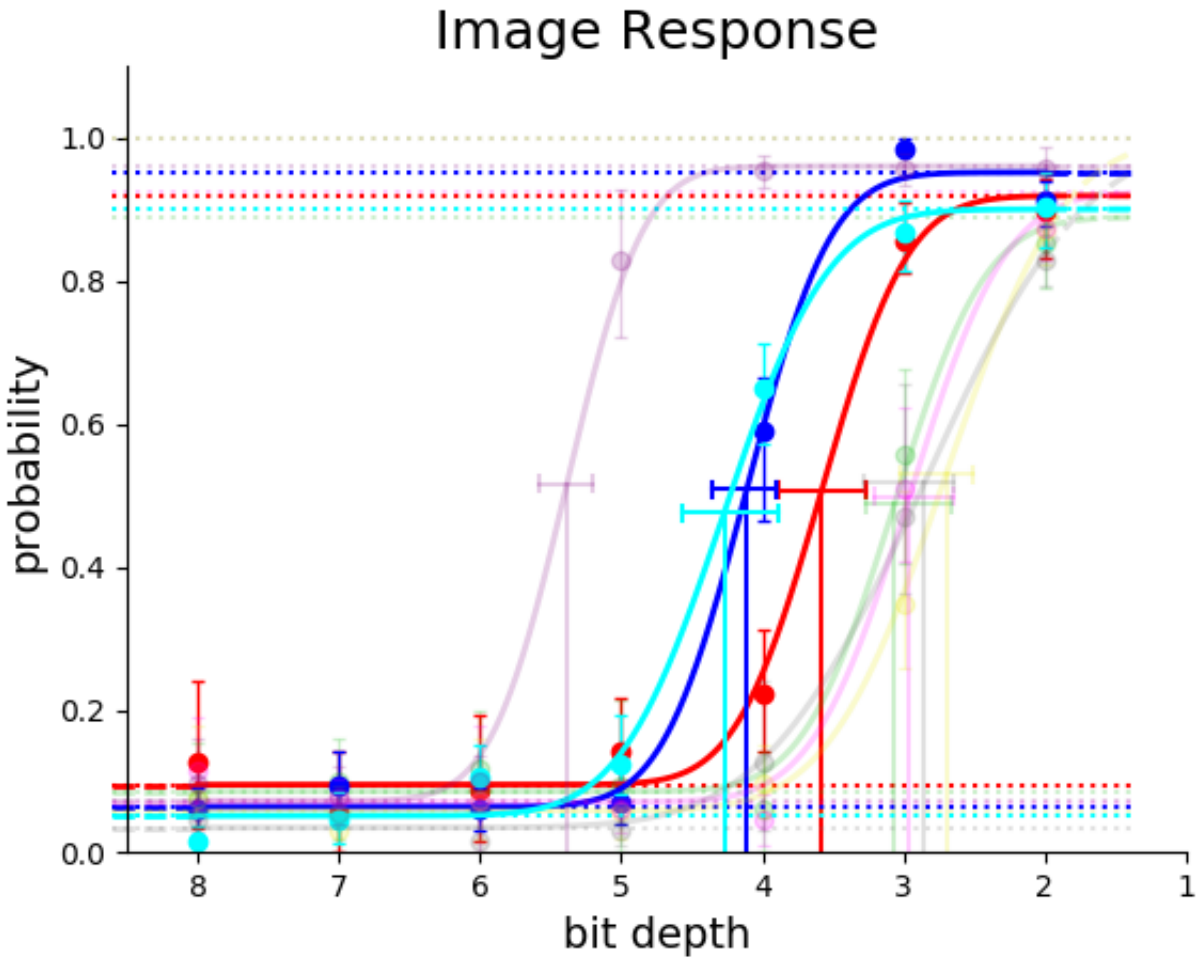
EXPERIMENT: REDUCE BIT DEPTH
WHEN DOES THE VIEWER SEE FOVEATION?



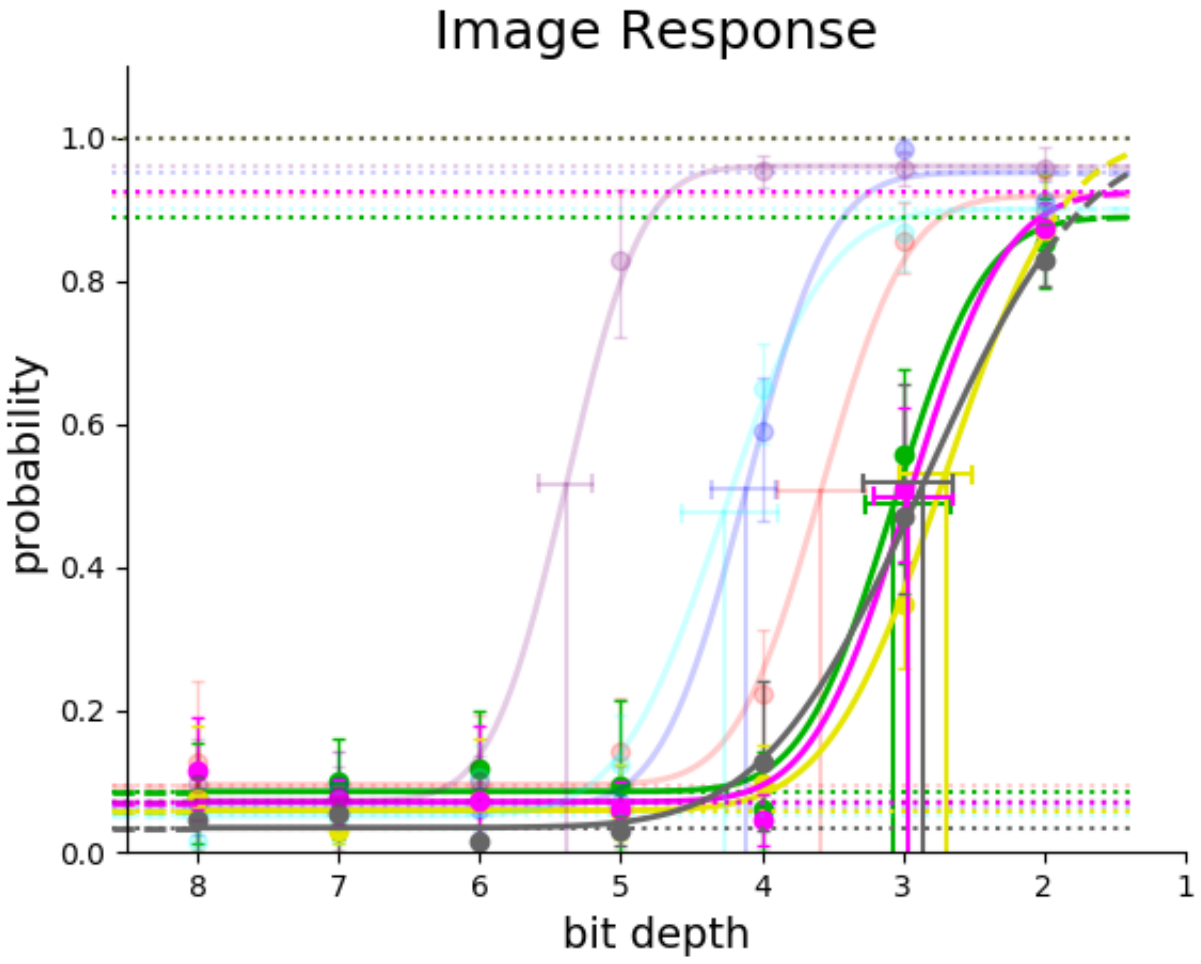
RESULT: LOW SPATIAL FREQUENCY CONTENT



RESULT: MID SPATIAL FREQUENCY CONTENT



RESULT: HIGH SPATIAL FREQUENCY CONTENT

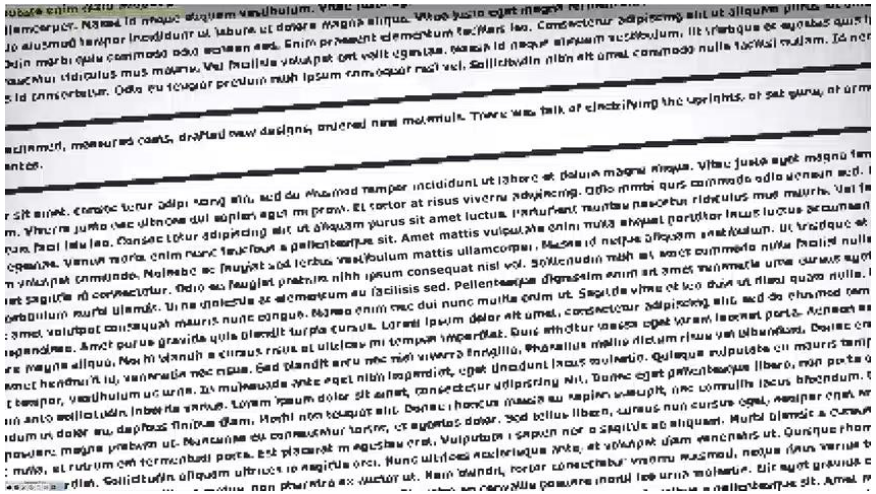


COLOR EXPERIMENT TAKEAWAY POINTS

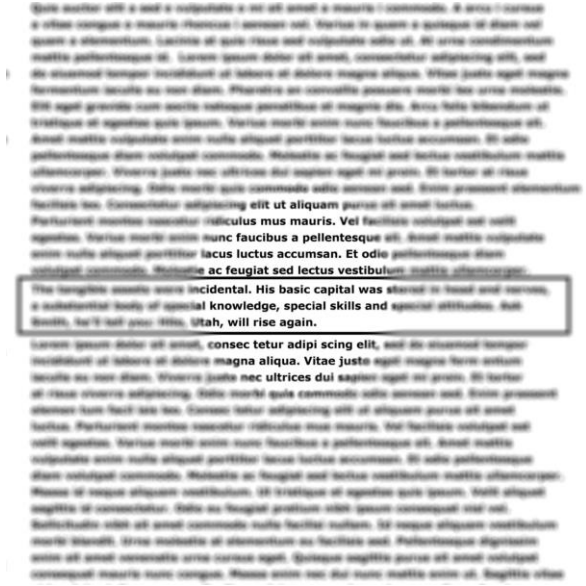
- Some bit depth reduction is not noticeable in the periphery
- The level of acceptable bit depth reduction is highly dependent on spatial frequency of the content

BIGGEST CHALLENGE: TEXT

High Contrast, High Spatial Frequency Content



Aliasing produces flicker



Blurring breaks contrast constancy

PERIPHERAL SPATIAL METAMERS

Original Image

Metamer #1

Metamer #2

Freeman & Simoncelli, 2011

PERIPHERAL SPATIAL METAMERS

- Lossy compression of spatial information
- Peripheral perception is complicated


NVIDIA
Almost
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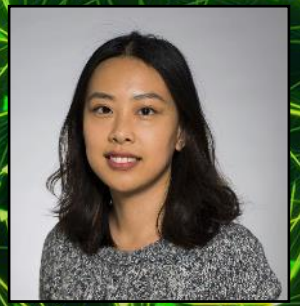
THANK YOU







NVIDIA

Almost

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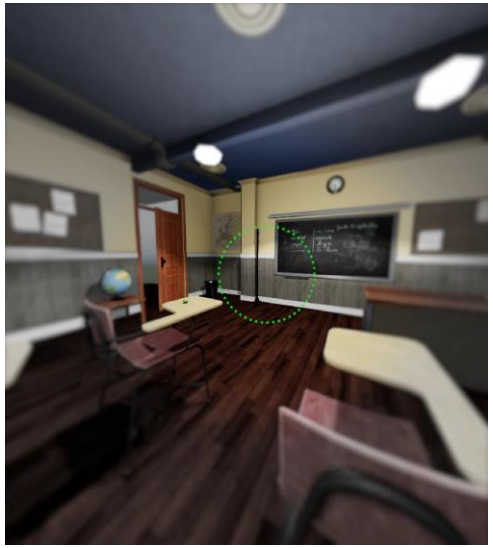
NVIDIA®

EXPERIMENTAL DESIGN

- Task – move eyes and head to try to see artifacts
  - 4 second stimulus duration per trial
  - Yes/No Response (“Did you see any artifacts?”)
- Amount of foveation varied based on responses
  - 1 up/ 1 down adaptive staircase
  - Foveation level = shading rate per 2^N pixels (higher is better)
- Controlled for actual system latency, head & eye motion

SYSTEM REQUIREMENTS FOR GAZE-CONTINGENT RENDERING



Eye Tracking

- Accurate
- Fast

Rendering

- Cheap, Fast
- Perceptually Matched

Display

- Low Persistence
- Low Latency