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Real-Time Ray Tracing on Head-Mounted-Displays for Advanced Visualization of Sheet Metal Stamping Defects

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Sheet Metal Forming

Applications in Manufacturing

- Sheet metal forming summarizes a number of metal forming techniques in mass manufacturing:
  - Stamping
  - Punching
  - Blanking
  - Embossing
  - Bending
  - Coining

- Most common raw materials to form are sheet metal, other applications include materials such as polysterene

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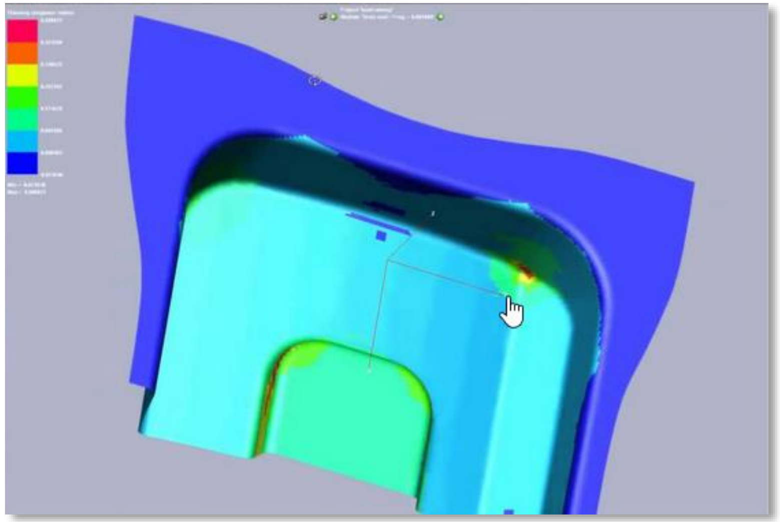
Sheet Metal Forming

Structural Defects

- Typical **structural** defects in sheet metal forming manufacturing
  - Cracking, splitting, ...
  - Springback
  - Wrinkles
  - Thinning / thickening

- Numerical solver solutions predict defects in stamped parts
  - Highly accurate simulation of the stamping process and die setup
  - Structural defects are clearly quantifiable
  - No physical prototype required



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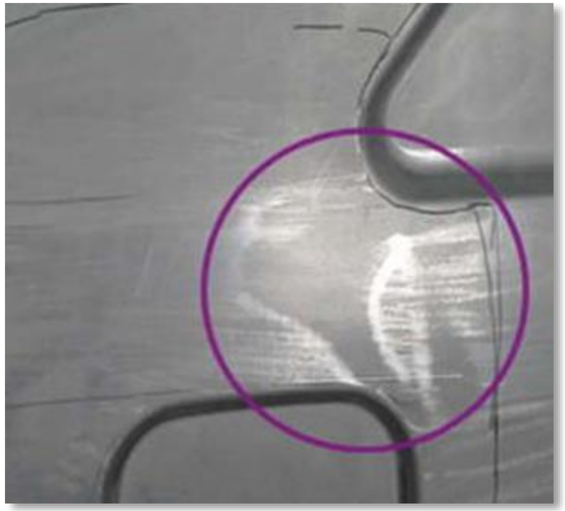
Sheet Metal Forming

Cosmetic Defects

- Aesthetics of remaining **cosmetic** defects hard to estimate from numerical analysis
- No general rule to automatically qualify based on numerics
  - Acceptance criteria vary from manufacturer to manufacturer and from model to model
  - Process builds on engineer’s expertise and experience
- Interpretation of the visual impact of a defect is highly subjective
- Further steps such as assembly, coating, paint, affect the visual impact of a defect



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Visualization of Cosmetic Stamping Defects

Physical Prototypes

- Prototype parts verified using a manual review process
  - Stamped part removed from the die, trimmed, put up on a holder, and brought to a mirror-like finish
  - Use of special lighting and a combination of viewpoint and interaction with the part to evaluate visual defects

- Try-out at time where changes to die and process are costly
  - Goal: zero physical prototypes
  - Virtually produce and inspect perceived quality – **before** try-out

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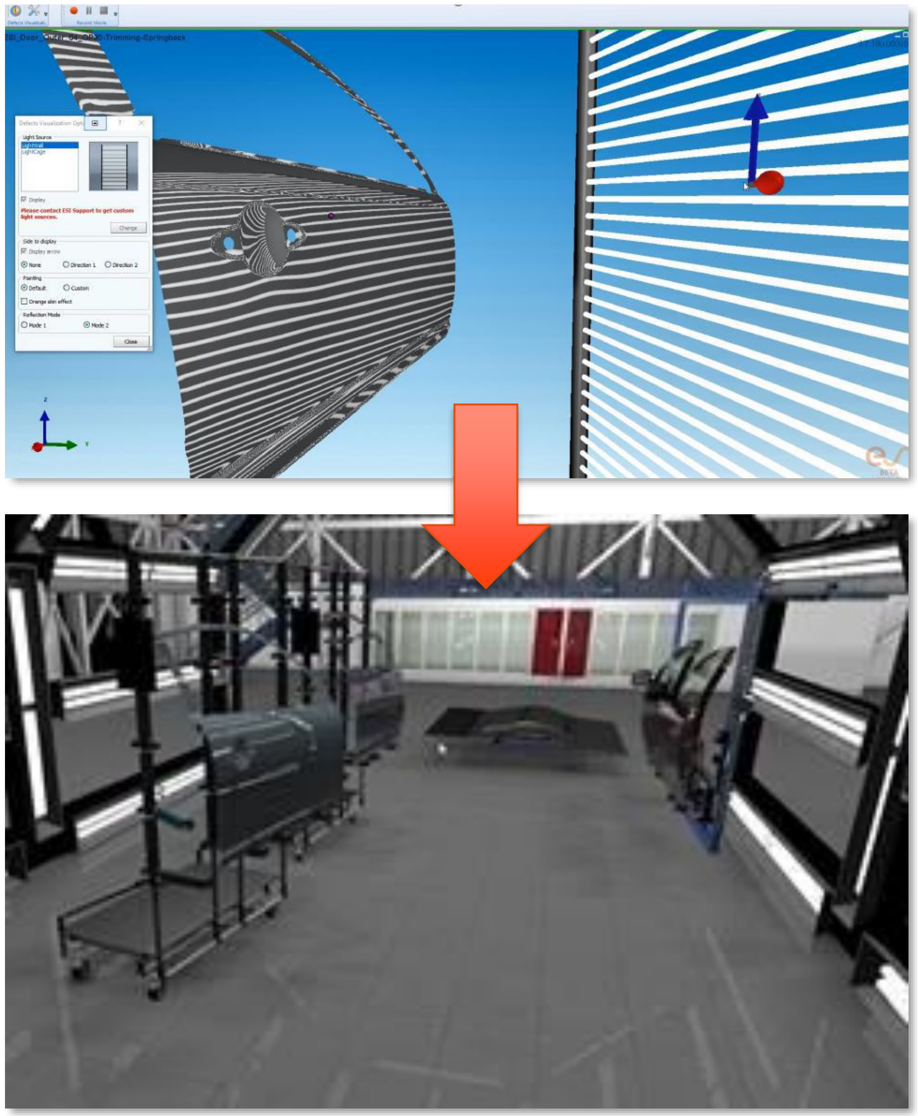
Visualization of Cosmetic Stamping Defects

Virtual Inspection

- Simulation of reflection lines
  - Reflection mapping (e.g. [Sussner et al. 2004])
  - Real-time ray tracing (e.g., [Wald et al. 2006])
    - So far limited to desktop applications
- New GPU Developments
  - RT Cores / Turing, DXR, Vulkan
  - Enable ray tracing applications in VR
    - Simulate accurate reflections at high resolutions and frame rates
    - Recreate whole physical workflows



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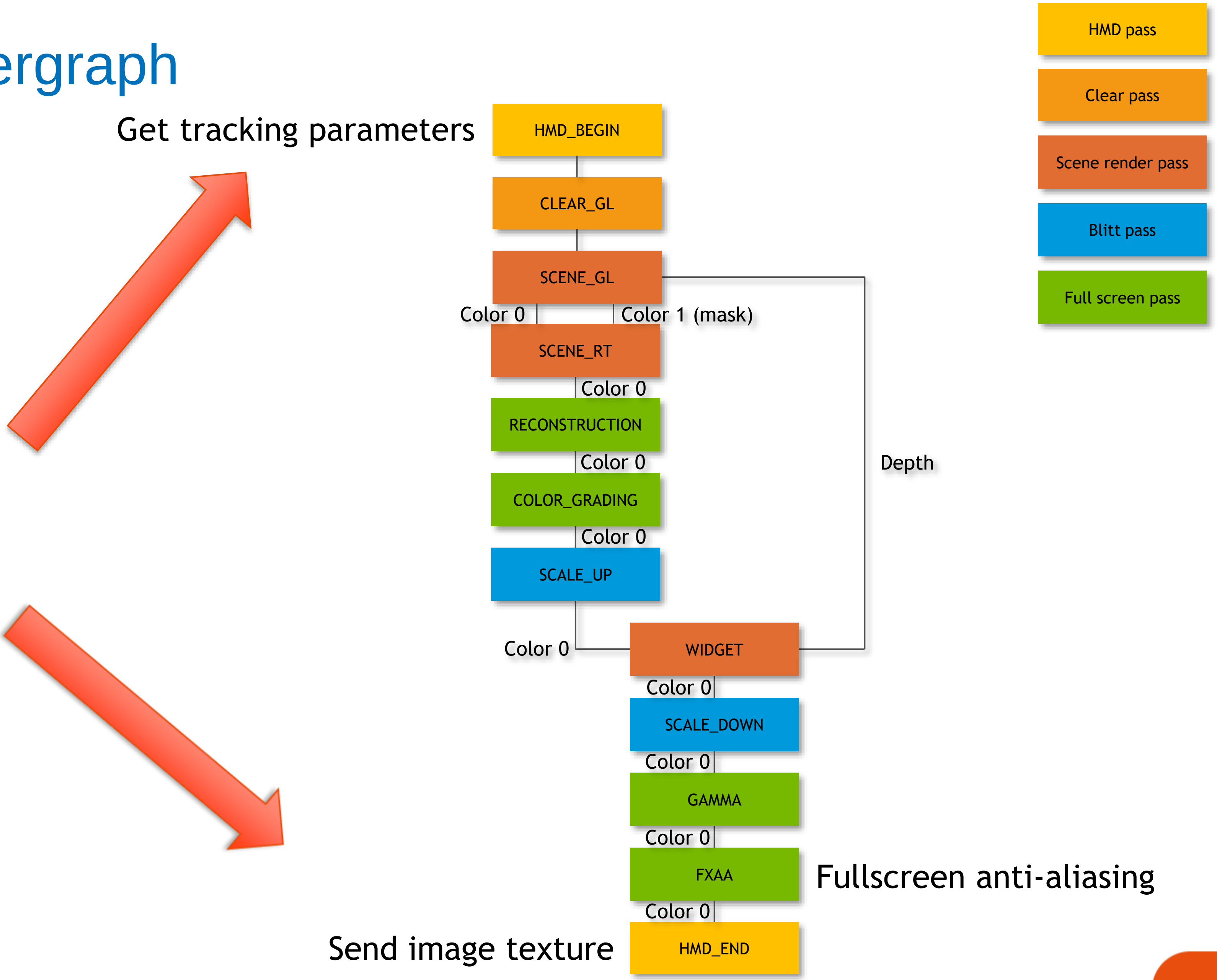
HMD Ray Tracing Rendergraph

- Communication with HMD
  - Part of renderer pipeline
  - Implemented as render passes
  - Latency reduction



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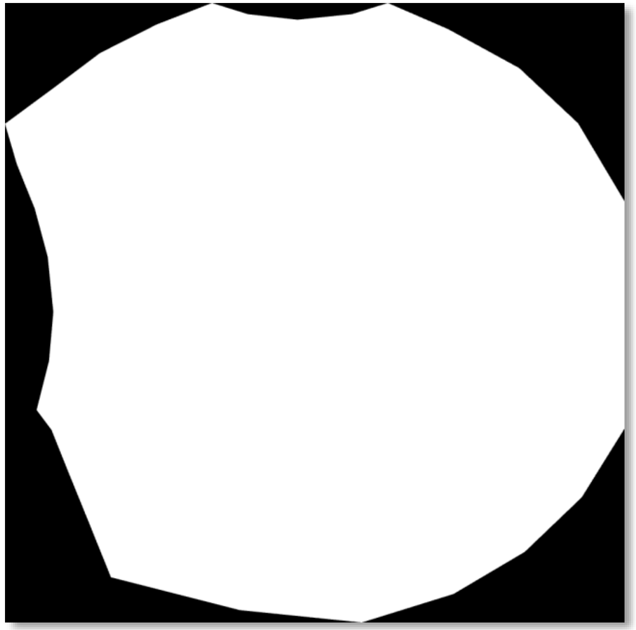
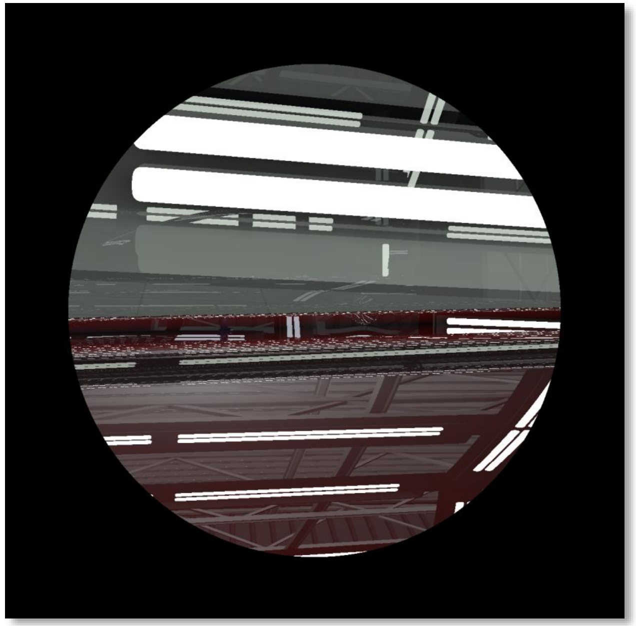
Vision Matched Rendering

Skipping invisible pixels

- Hidden Area Mesh
  - Provided by OpenVR SDK
  - Defines visible area within image
  - Depends on HMD optics (e.g., lens distortion)
  - Roughly circular on Vive Pro

- Exploit in OptiX ray generation program
  - Avoid visibility computation **and** shading
  - Skip computing pixels outside disc
  - Disc diameter about 80% of box width





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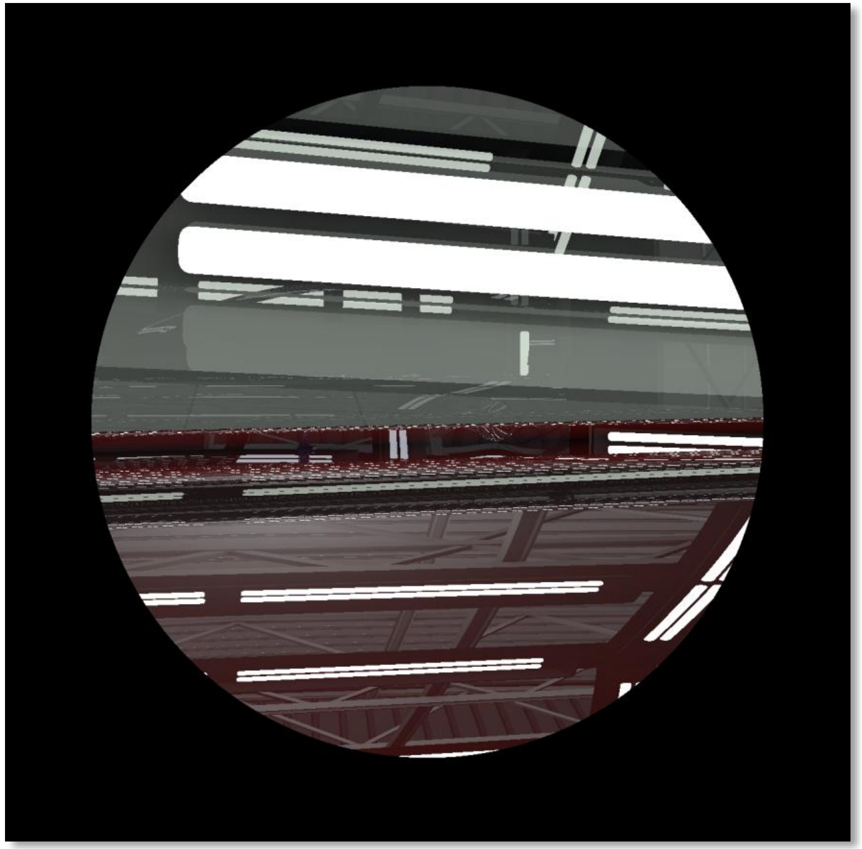
Aliasing



- Causes strong flickering
- More objectionable than stutter
- Particularly visible in reflections on curved surfaces

AA techniques implemented:

Basic oversampling

Render at higher resolution

➢ Reduce overall flicker

Foveated oversampling

More samples at image center

➢ Reduce flicker of reflections

FXAA

Filtering post-process

➢ Smooth edges

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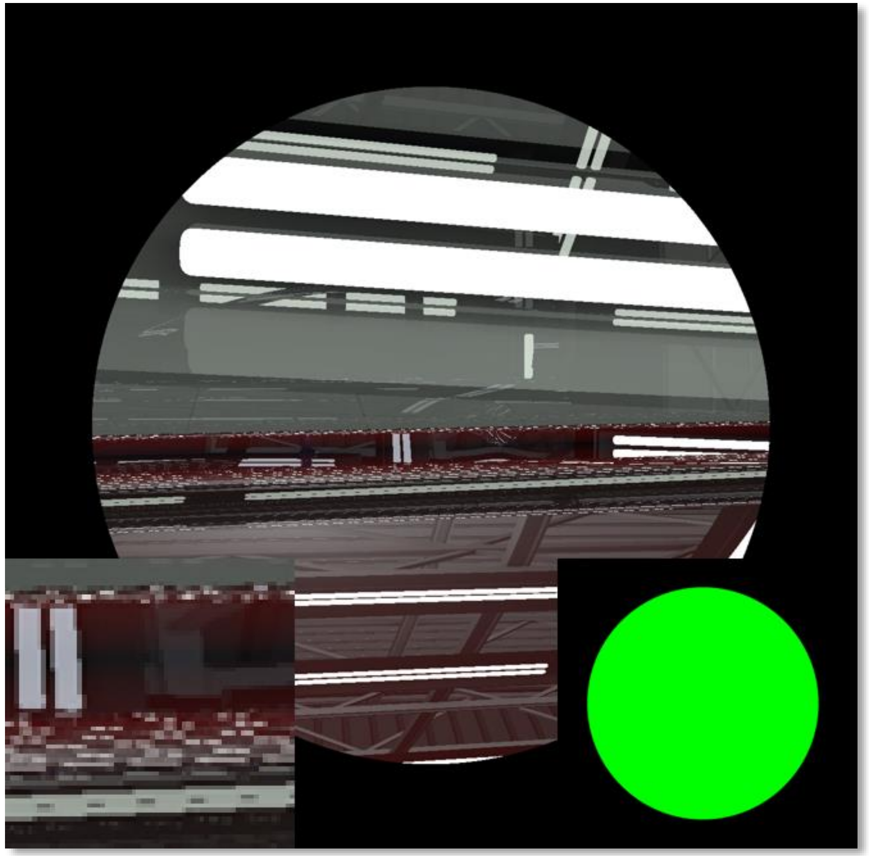
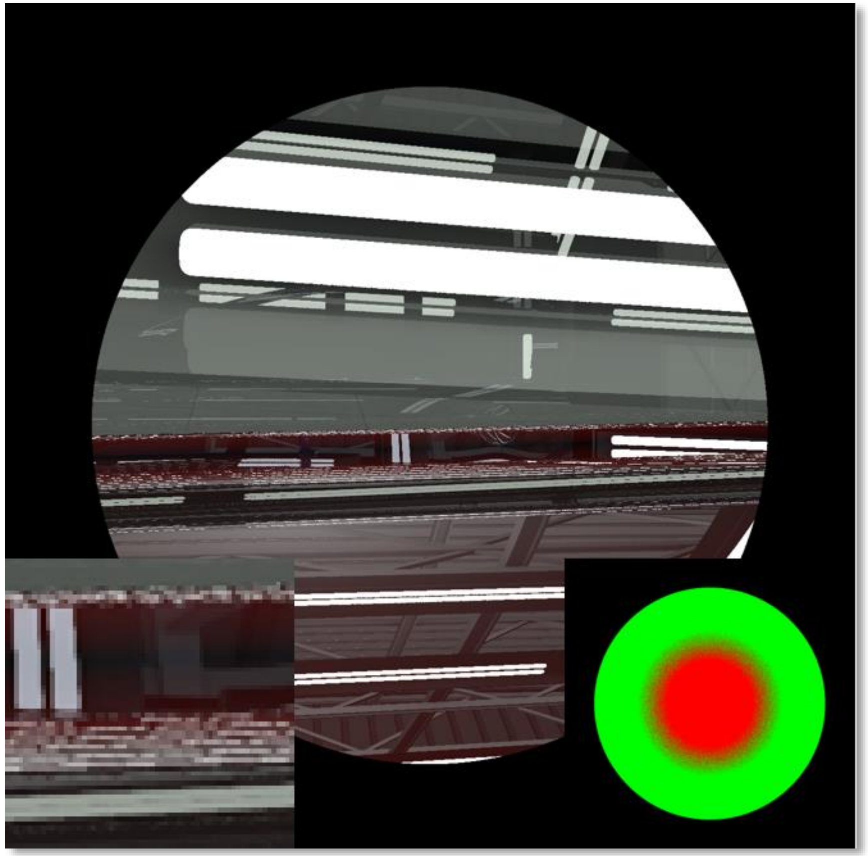
Foveated Rendering

Experimental Variable Rate Sampling





Green: 1 sample / pixel
Red: 4 samples / pixel

- Foveated oversampling
  - 50% radius of visible area disc
  - Dithering to avoid sharp transition
  - 4 samples / pixel
  - Still strong flicker
  - Frame rate reduced to ~10 fps
  - Need more than 16 for significant impact
  - **Not** practical

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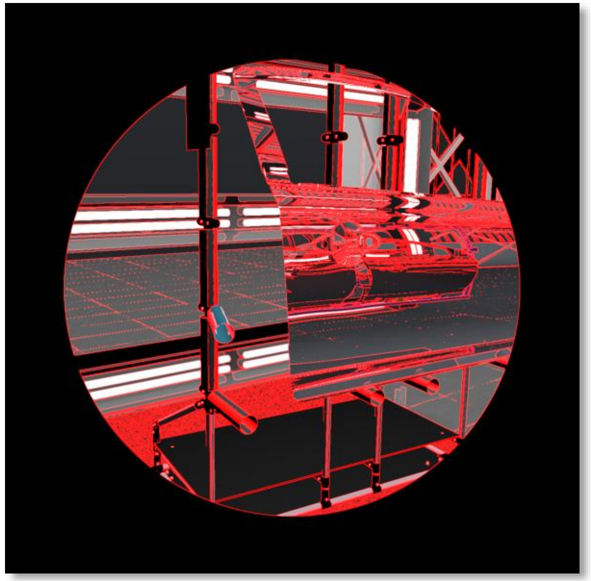
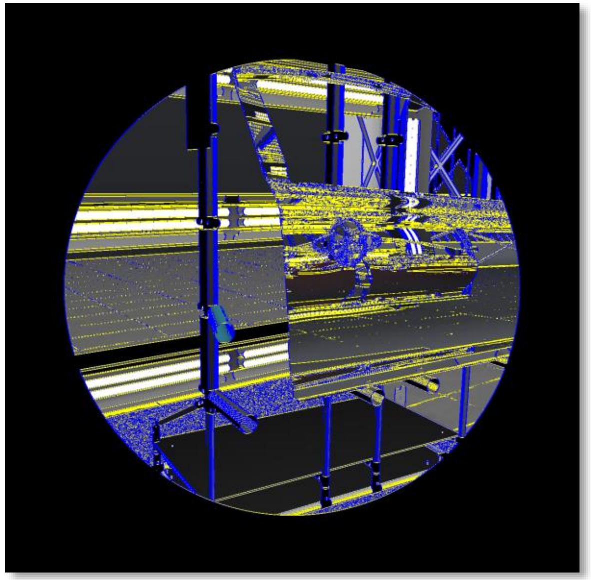
Anti-Aliasing

Fast ApproXimate Anti-Aliasing (FXAA)

- FXAA [Lottes 2009]
  - Fullscreen post process (GLSL)
  - Edge-aware low-pass filter
- Basic algorithm
  - Detect edges based on contrast difference
  - Approximate luminance gradient
  - Filter along axis perpendicular to gradient



Edge detection



Main filtering direction

blue: vertical
yellow: horizontal

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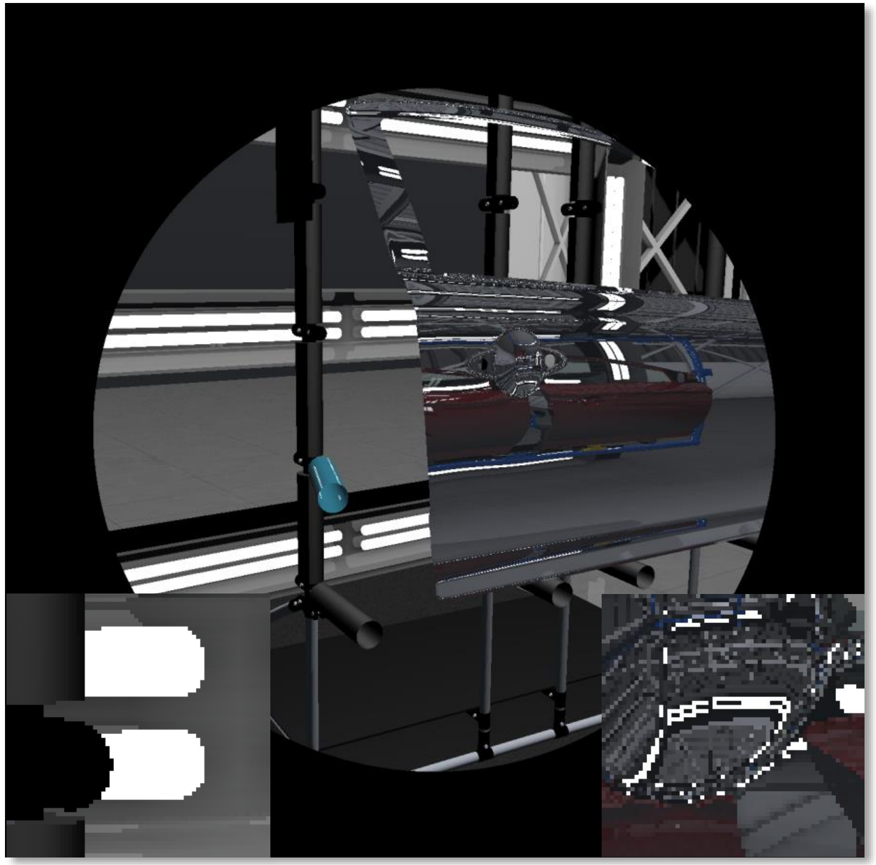
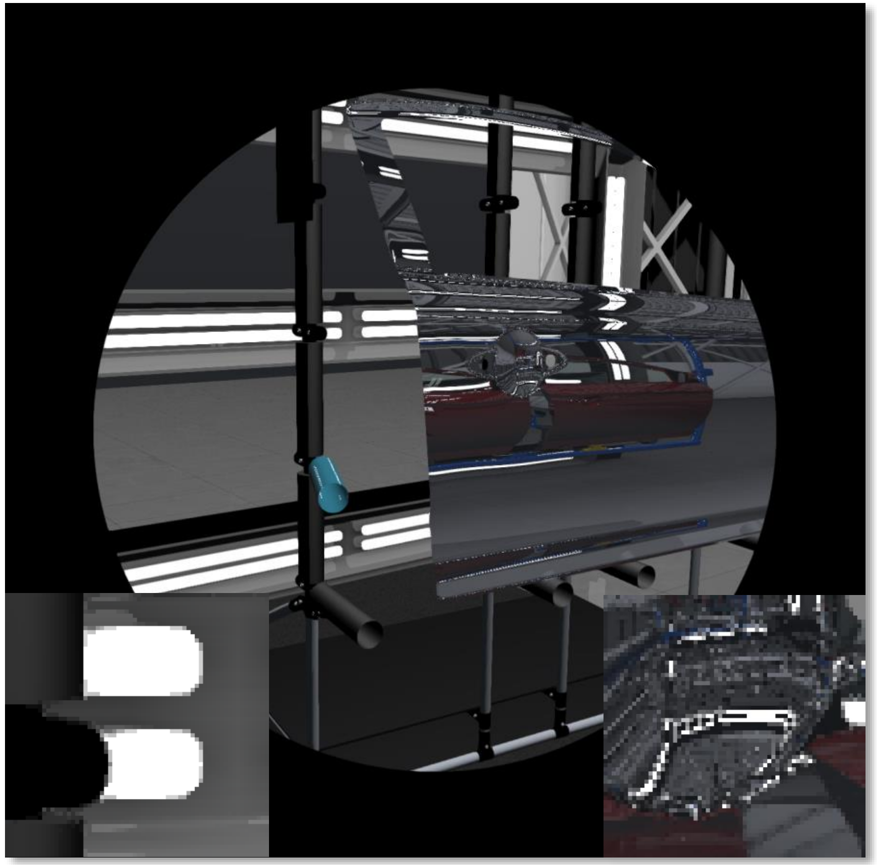


Without FXAA



With FXAA

- FXAA post-process
  - Works well for edges
  - Does not help for light reflections
  - Smooths light fragments but does not merge them

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System Setup

GPU

- NVIDIA Quadro RTX 8000
  - Turing architecture
  - 4608 CUDA cores
  - 576 Tensor cores
  - 72 RT cores
  - 48 GB device memory

HMD

- HTC Vive Pro
  - 1440 x 1600 pixels per eye
  - 90 Hz refresh rate
  - 110 degrees field of view

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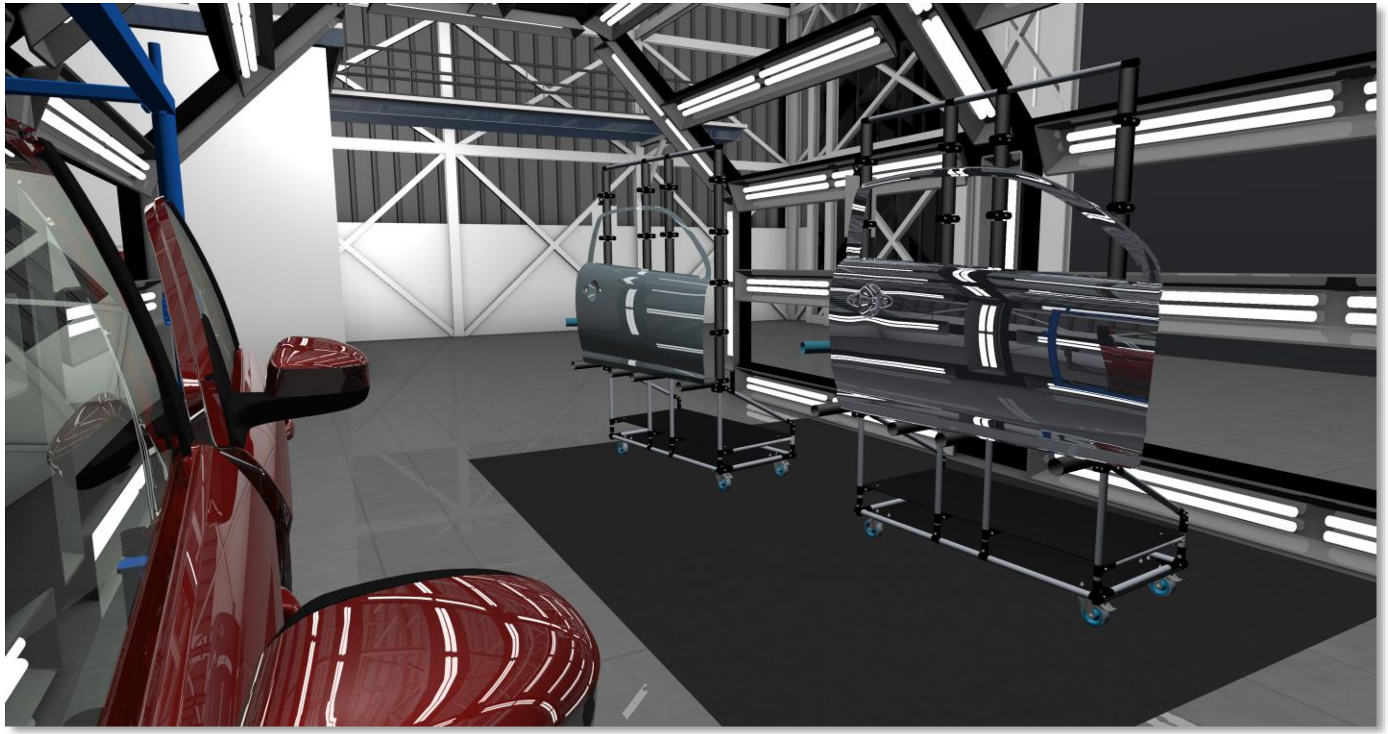
Performance Results

- Demo Scene
  - 2.2 Mio triangles
  - 1000 individual objects
  - 3 levels of reflection
  - 1 point light
  - Baked ambient occlusion

- Ray tracing backend provides
  - 2016 x 2240 pixels per eye
    - Super-sampled anti-aliasing
    - 100% resolution in SteamVR settings
    - Filtering done by HMD
  - 20 – 45 fps
    - HMD performs asynchronous reprojection to reduce judder



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Experiences and Conclusion

- Full-frame Whitted-style ray tracing feasible on HMDs with a single GPU
  - Usable in VR inspection scenarios in virtual prototyping

- Raw frame rate not as important as you might think
  - Asynchronous reprojection works well for framerates above 20 fps
  - Significant change in stutter only perceived below 20 fps or over 90 fps

- Flicker resulting from aliasing most significant issue
  - Noise-type aliasing in reflections
  - Edge-filtering not sufficent
  - Vision matched oversampling still too costly

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QUESTIONS?

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