



Multi-Camera Systems for AR / VR and Depth Sensing

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IS&T Electronic Imaging 2018
Photography, Mobile, and Immersive Imaging

OVERVIEW

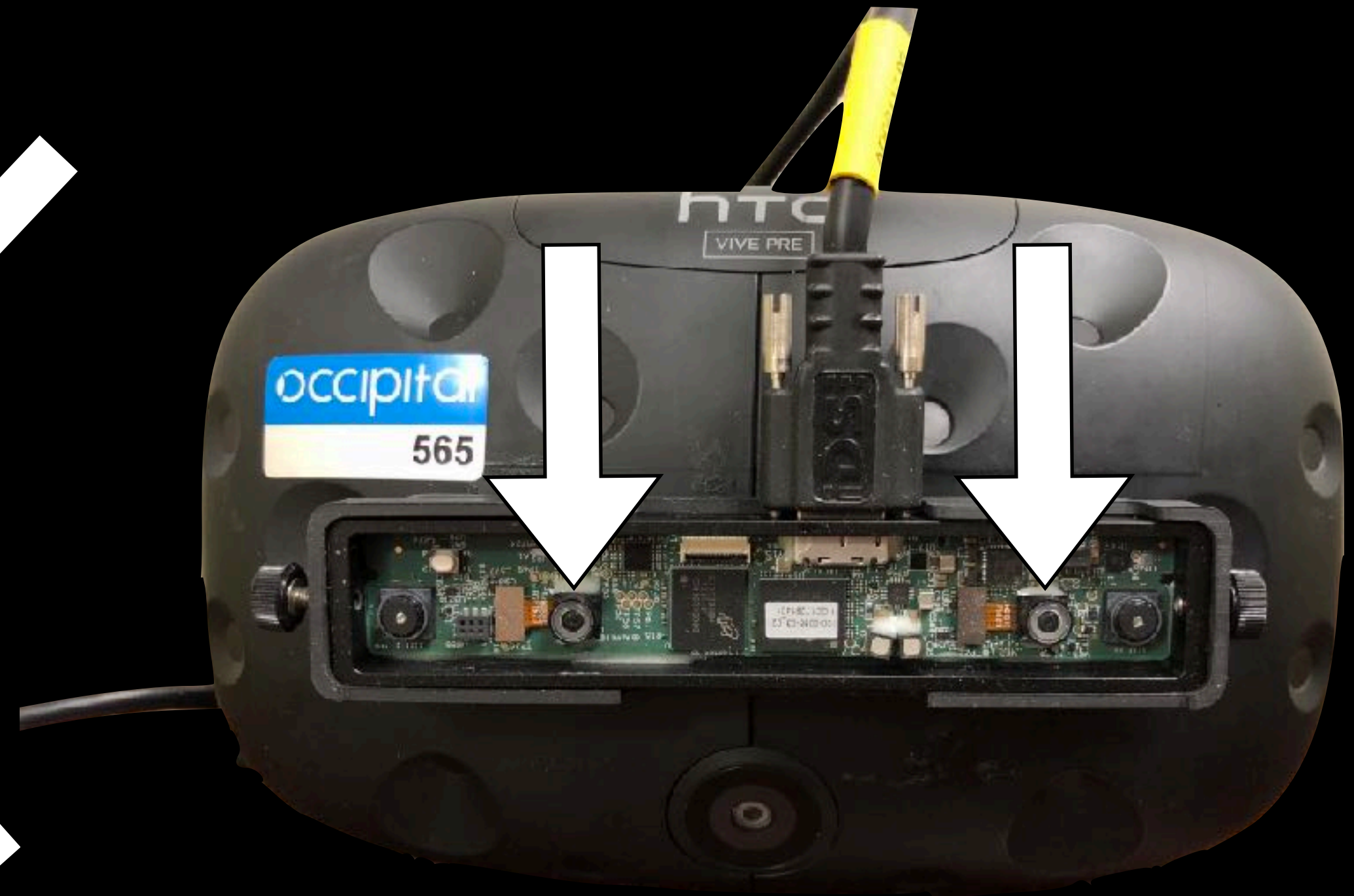
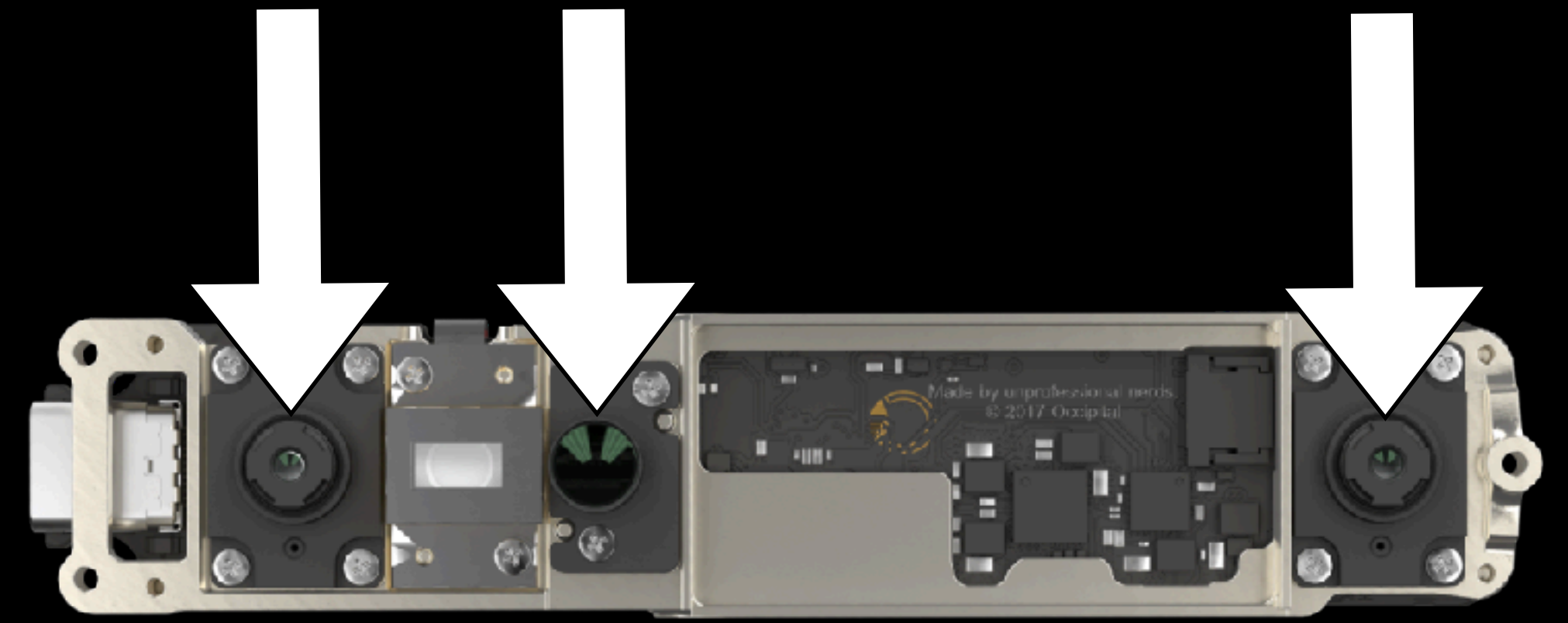
- Integrated SLAM Systems - Hardware & Software
- System Calibrations & Relationships
 - Photometric, Geometric, & Temporal Considerations
- “Wish List” for future AR/VR-focused imaging systems





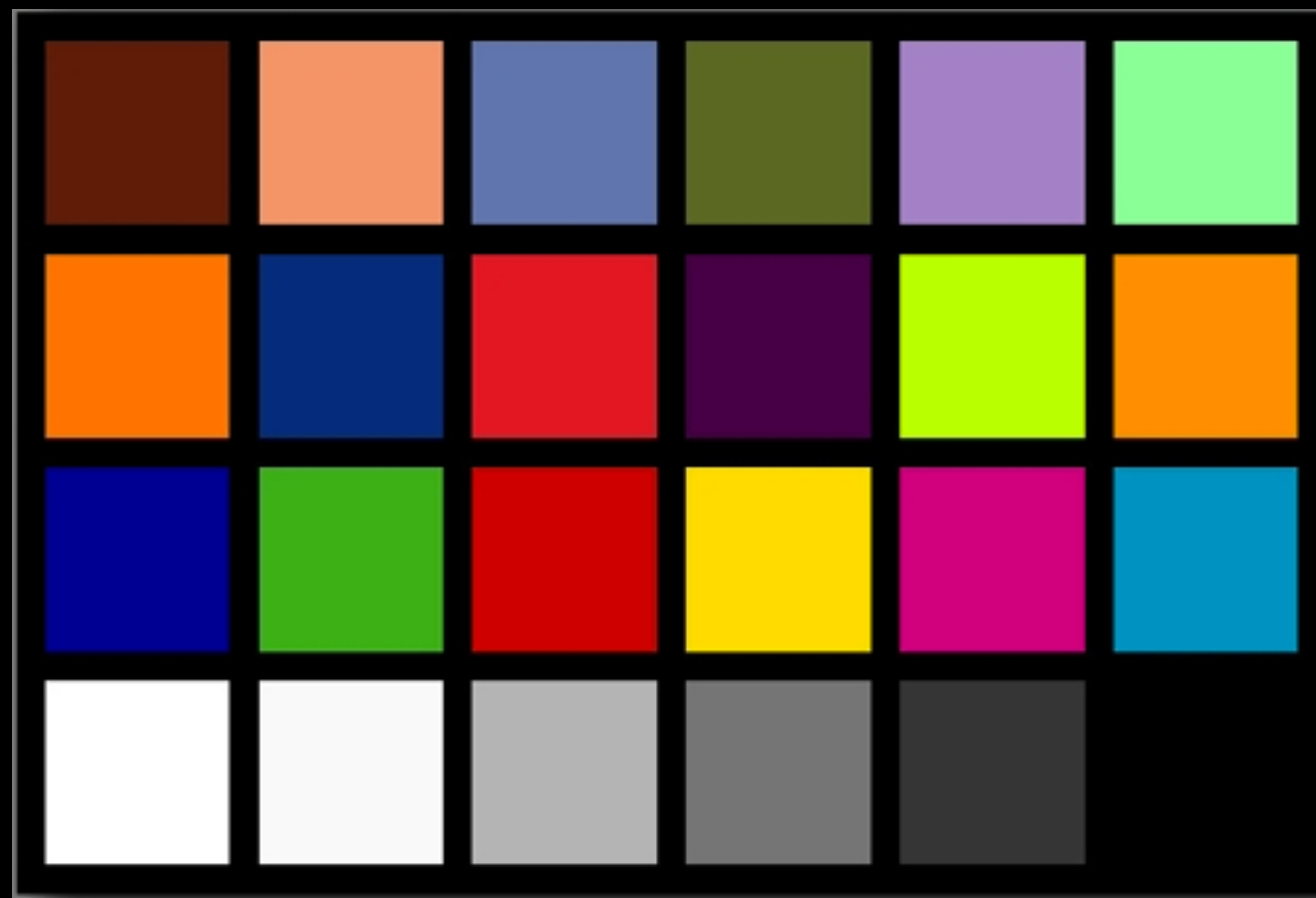


HARDWARE



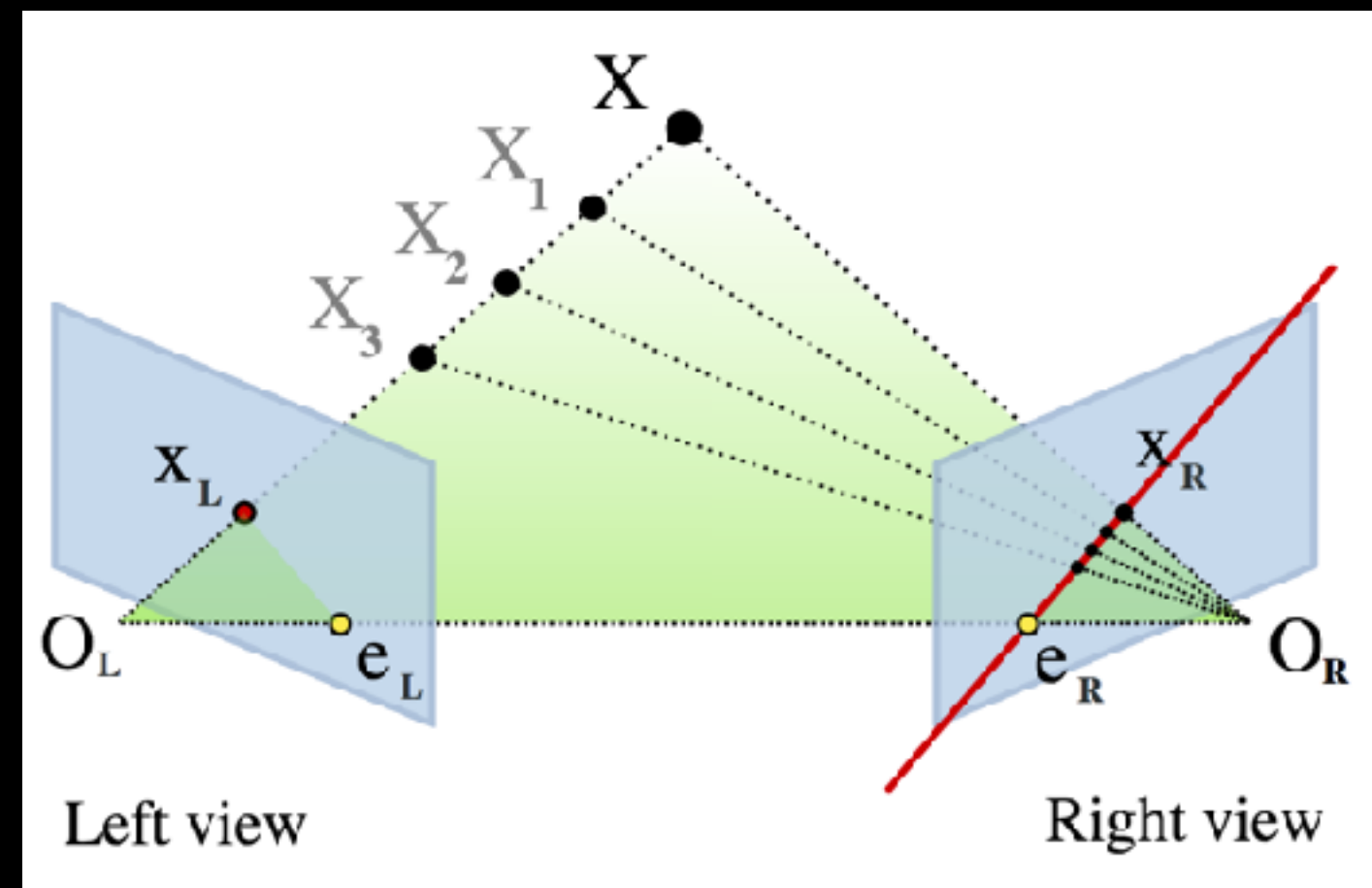
SYSTEM RELATIONSHIPS & CALIBRATIONS

Photometric



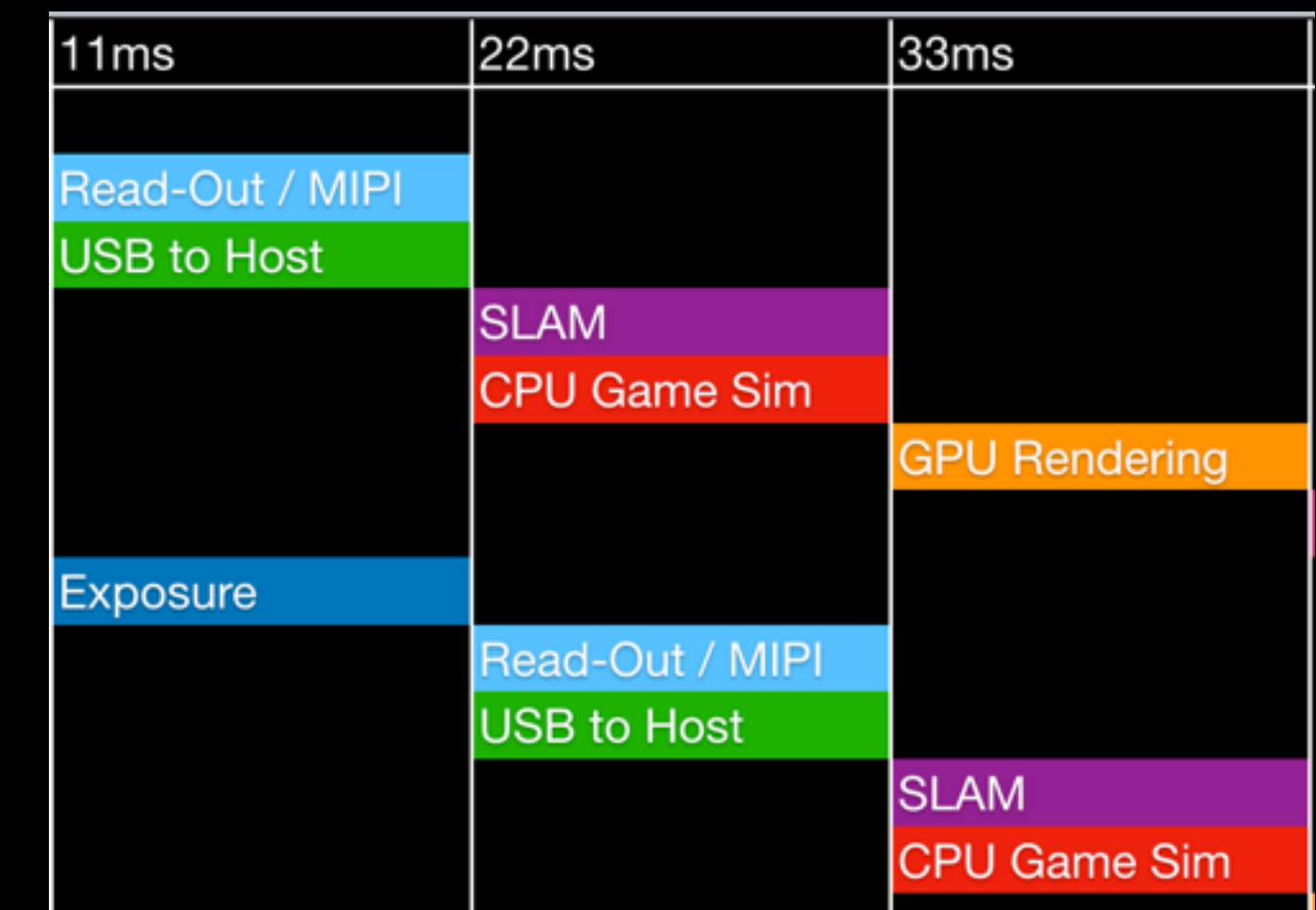
Color Balance
Sensitivity
Noise

Geometric



Camera Intrinsics
Camera-to-Camera
Camera-to-Display

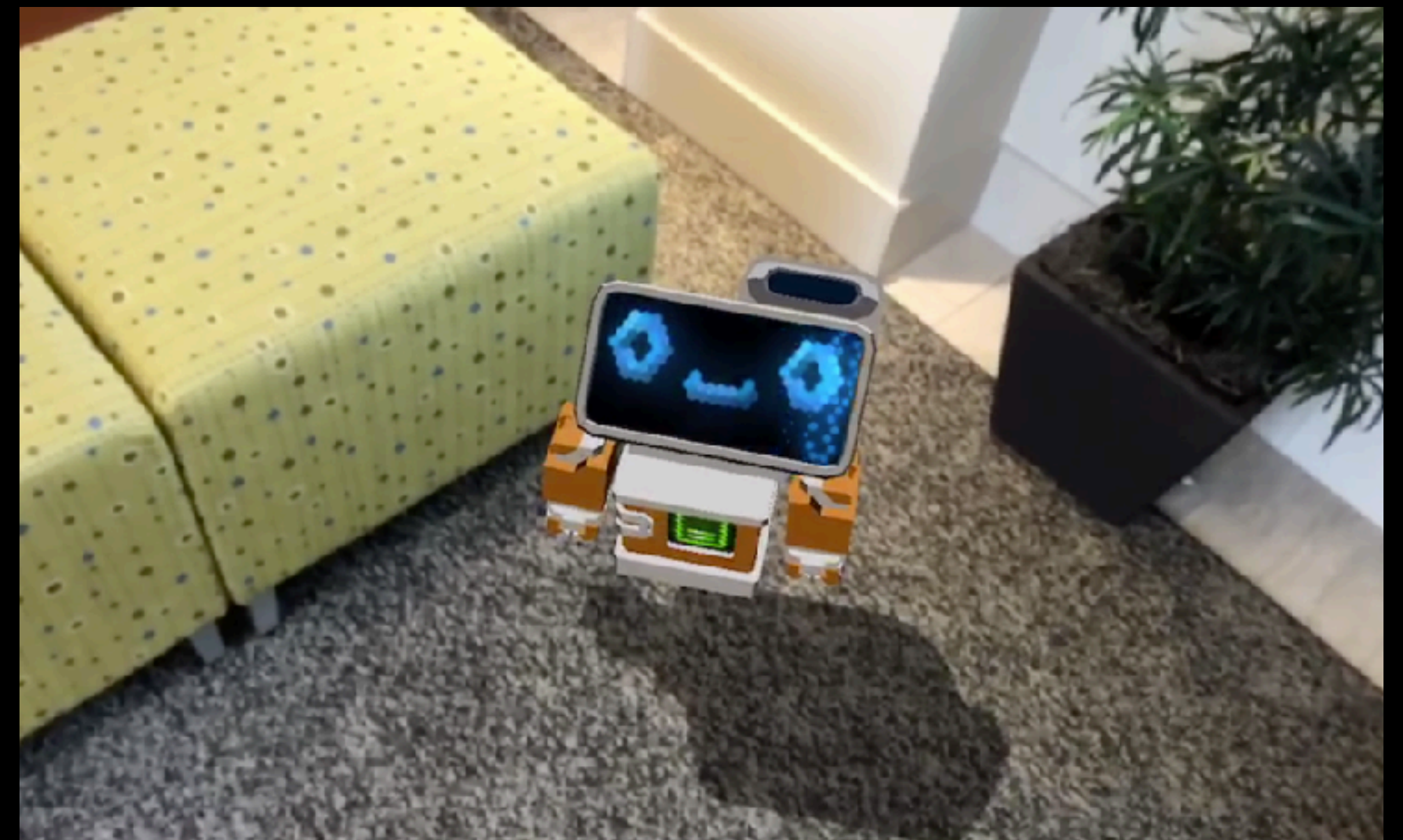
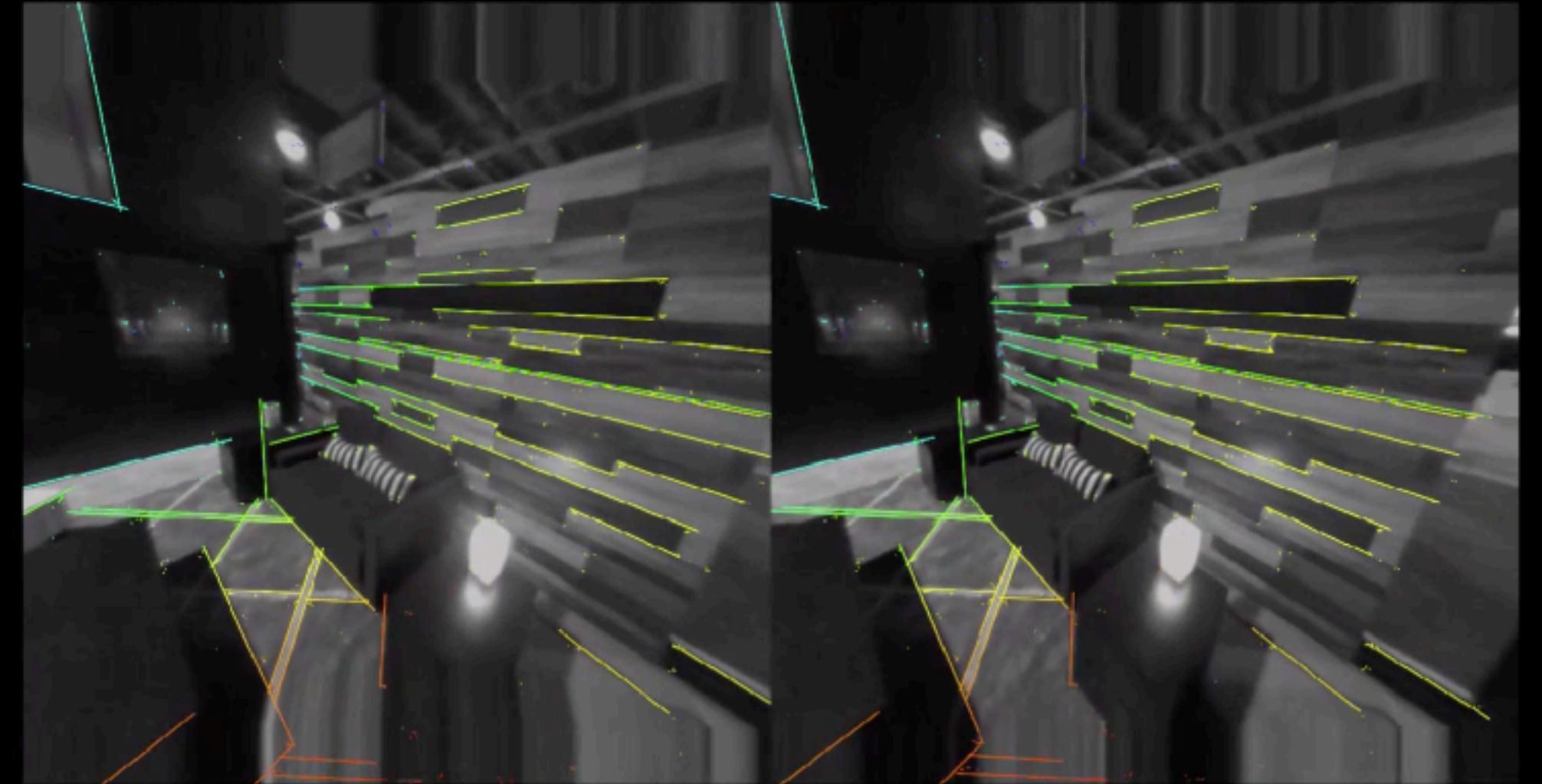
Temporal



Synchronization
Group Delays
Latency

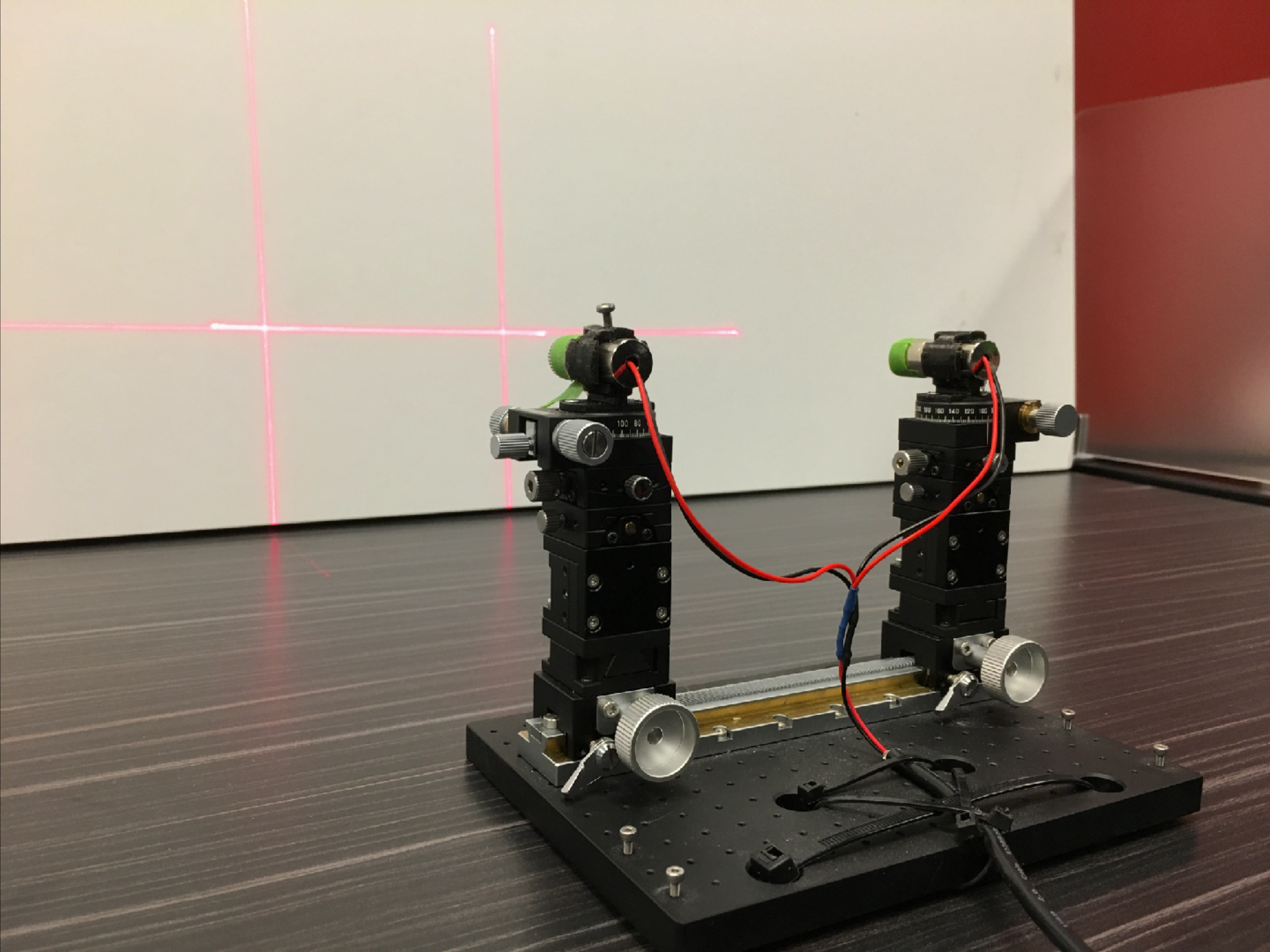
PHOTOMETRIC

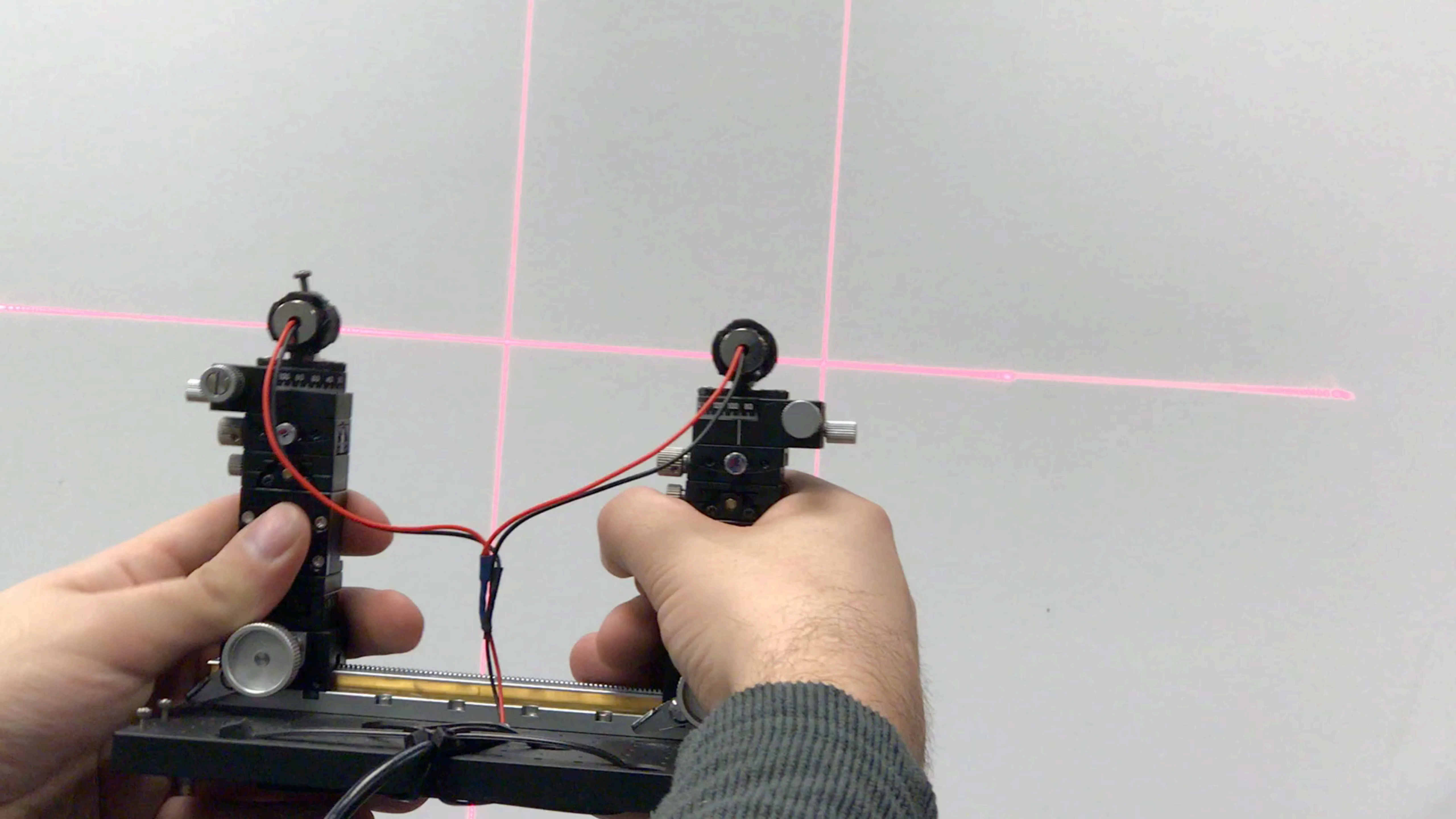
- SLAM Considerations
 - Correlations / Repeat Observations
 - Image Stability (Noise)
- Augmented / Mixed Reality Display
 - Color Calibration
 - Sharpness / Focus



GEOMETRIC

- Intrinsic Calibration
 - Lens Intrinsic — IMU intrinsic — Display Distortions
- Extrinsic Calibration
 - Camera to Camera — Camera to IMU — Camera to Display
- Live Calibration / Real-Time Variances

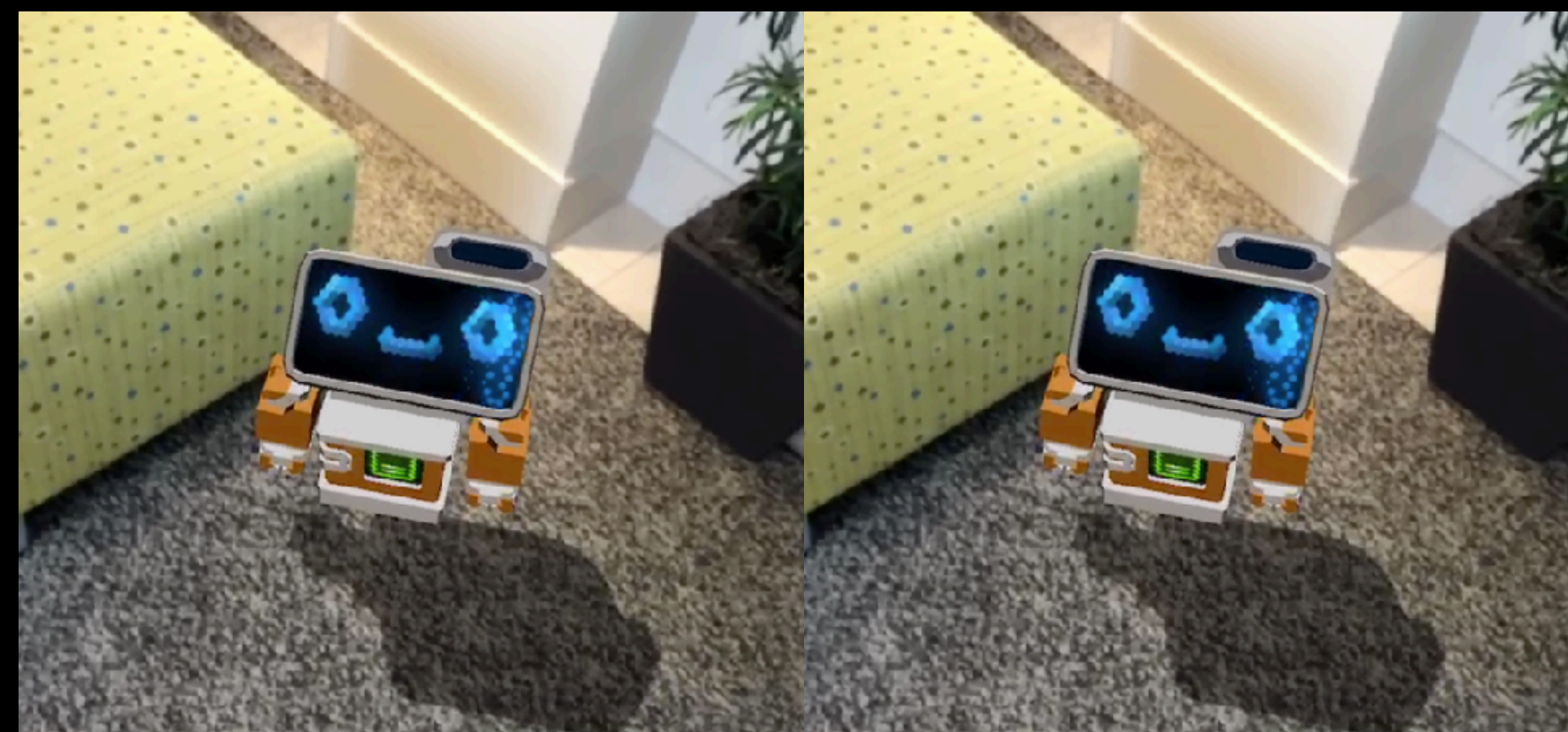




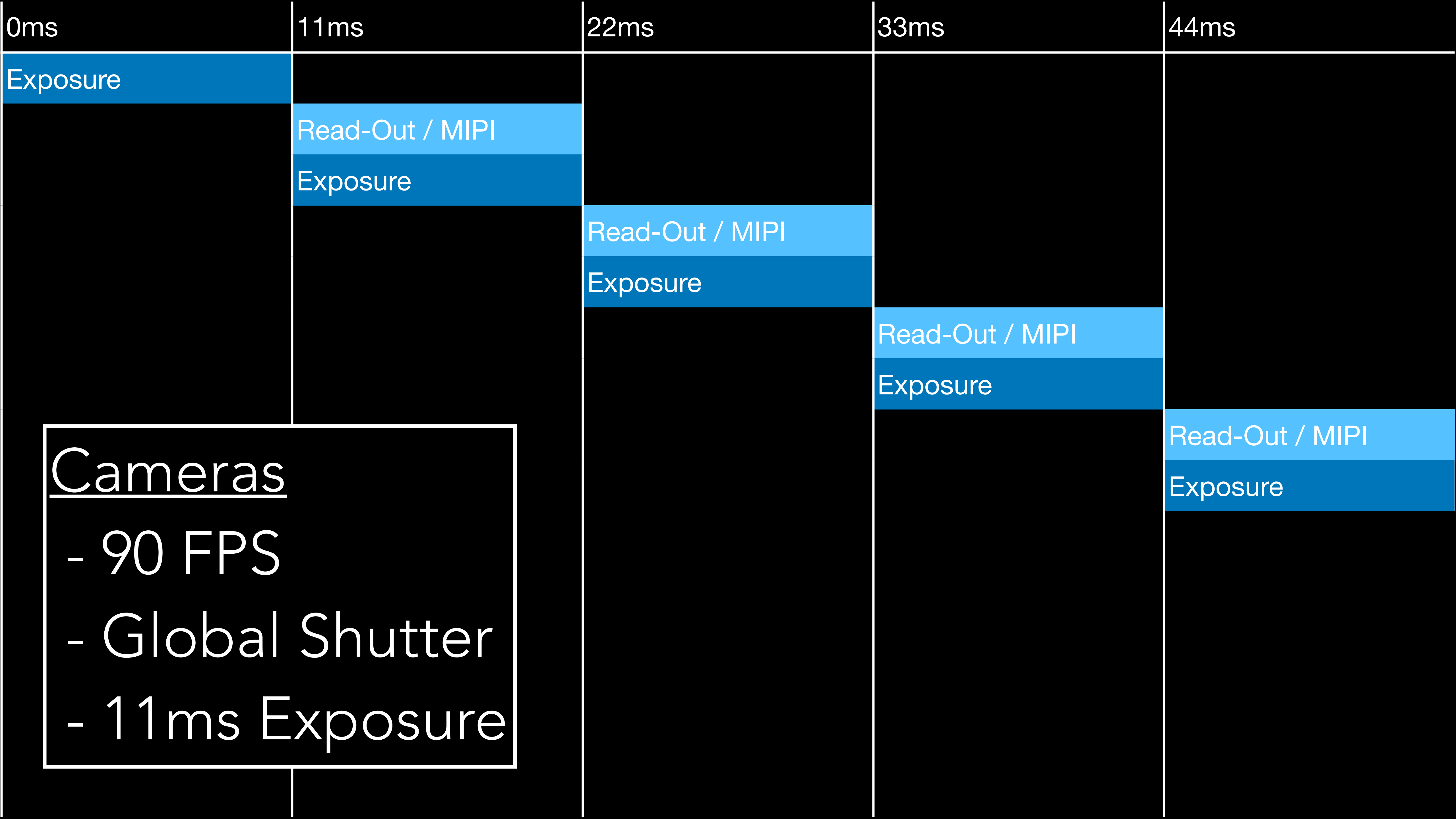
TEMPORAL

- Synchronization: Camera pairs — Camera / IMU data
- System-Level Timestamps for All Data & Events
 - IMU packets — Camera exposures — Display timing
- Latency Characterization & Compensation
 - IMU bandwidth — Data transfer — Frame readout — SLAM / Tracking
 - Game Simulation & Rendering — Display Link Latency

TEMPORAL — EXAMPLE SYSTEM

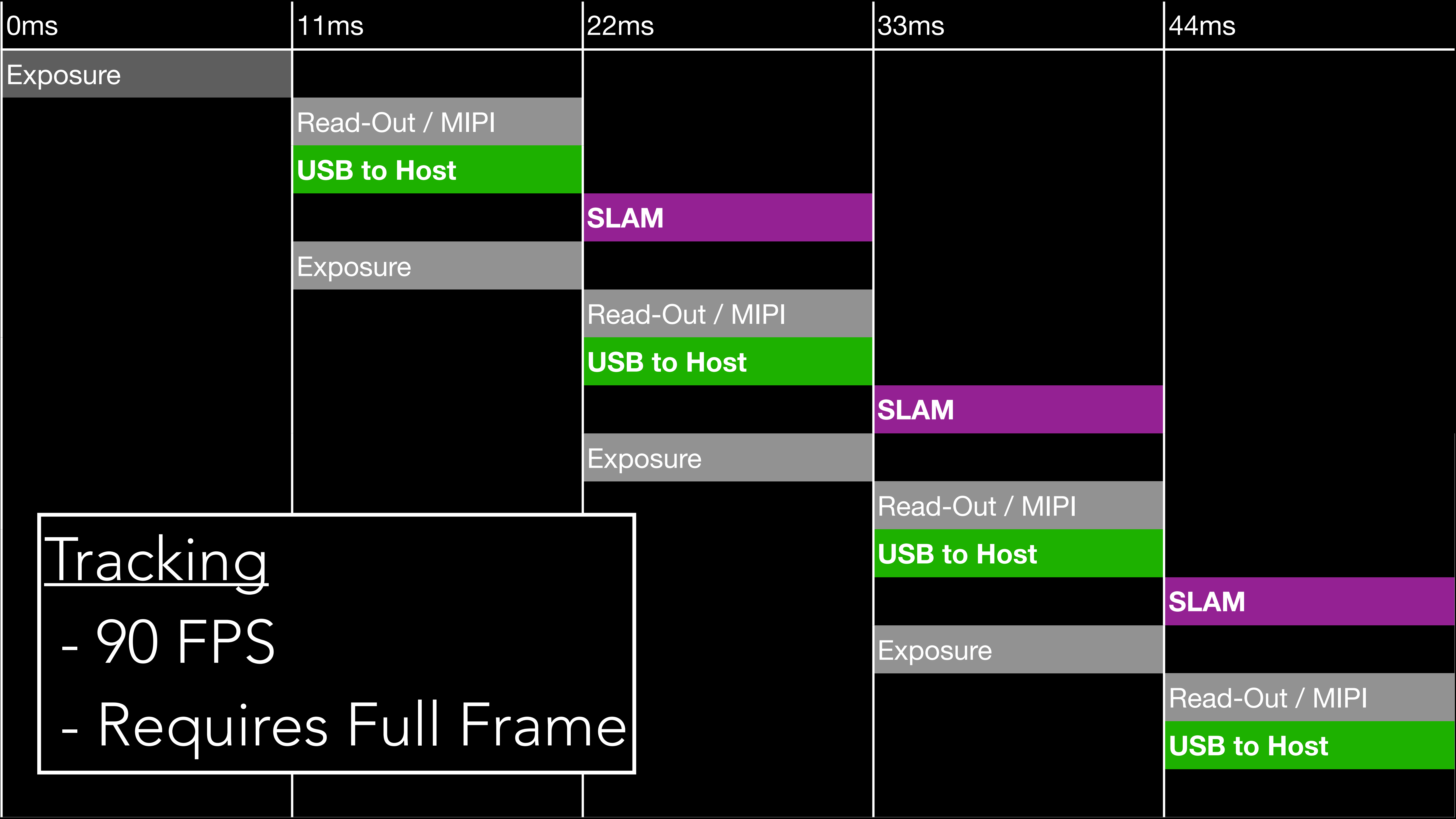




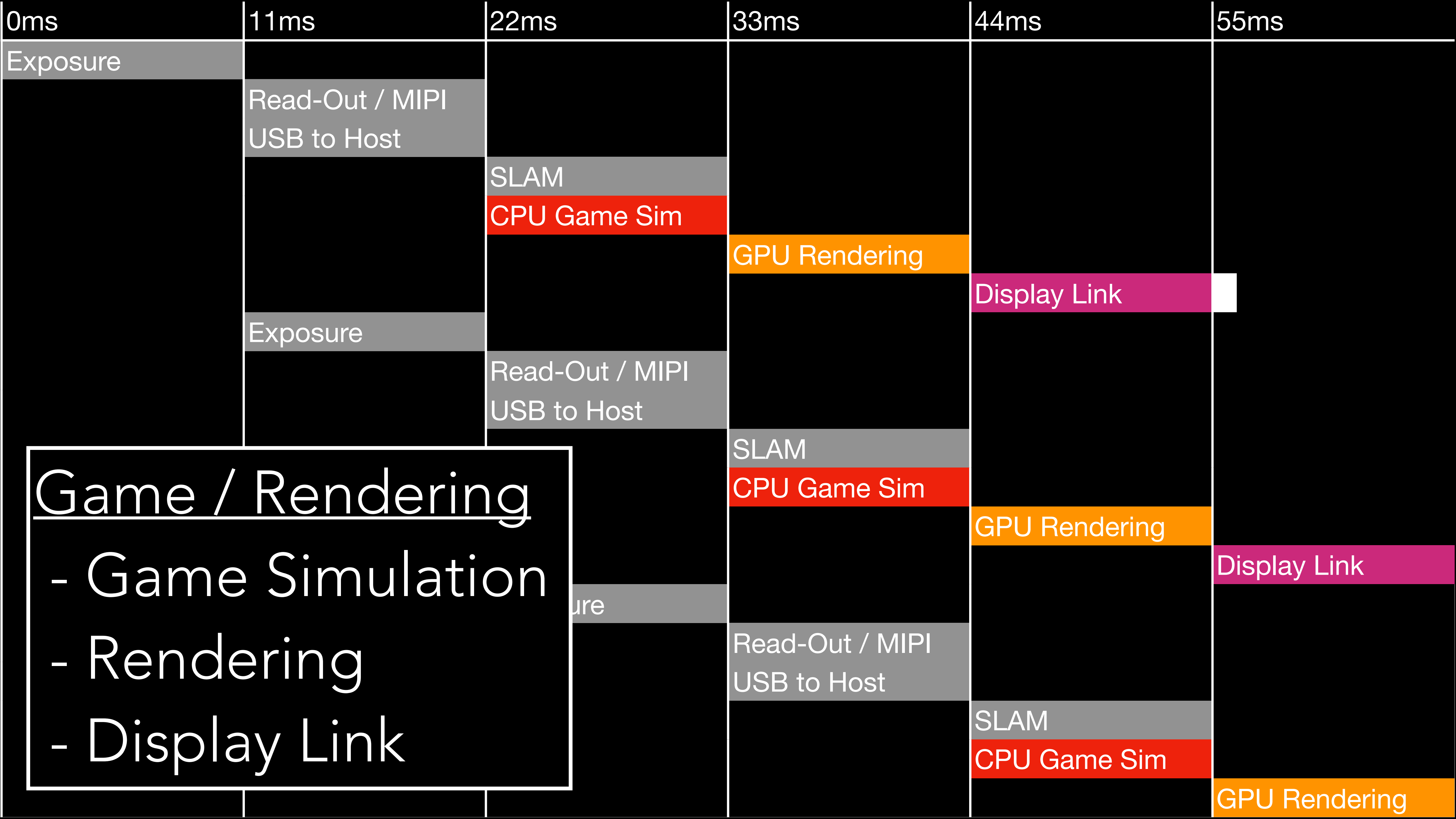


Cameras

- 90 FPS
- Global Shutter
- 11ms Exposure

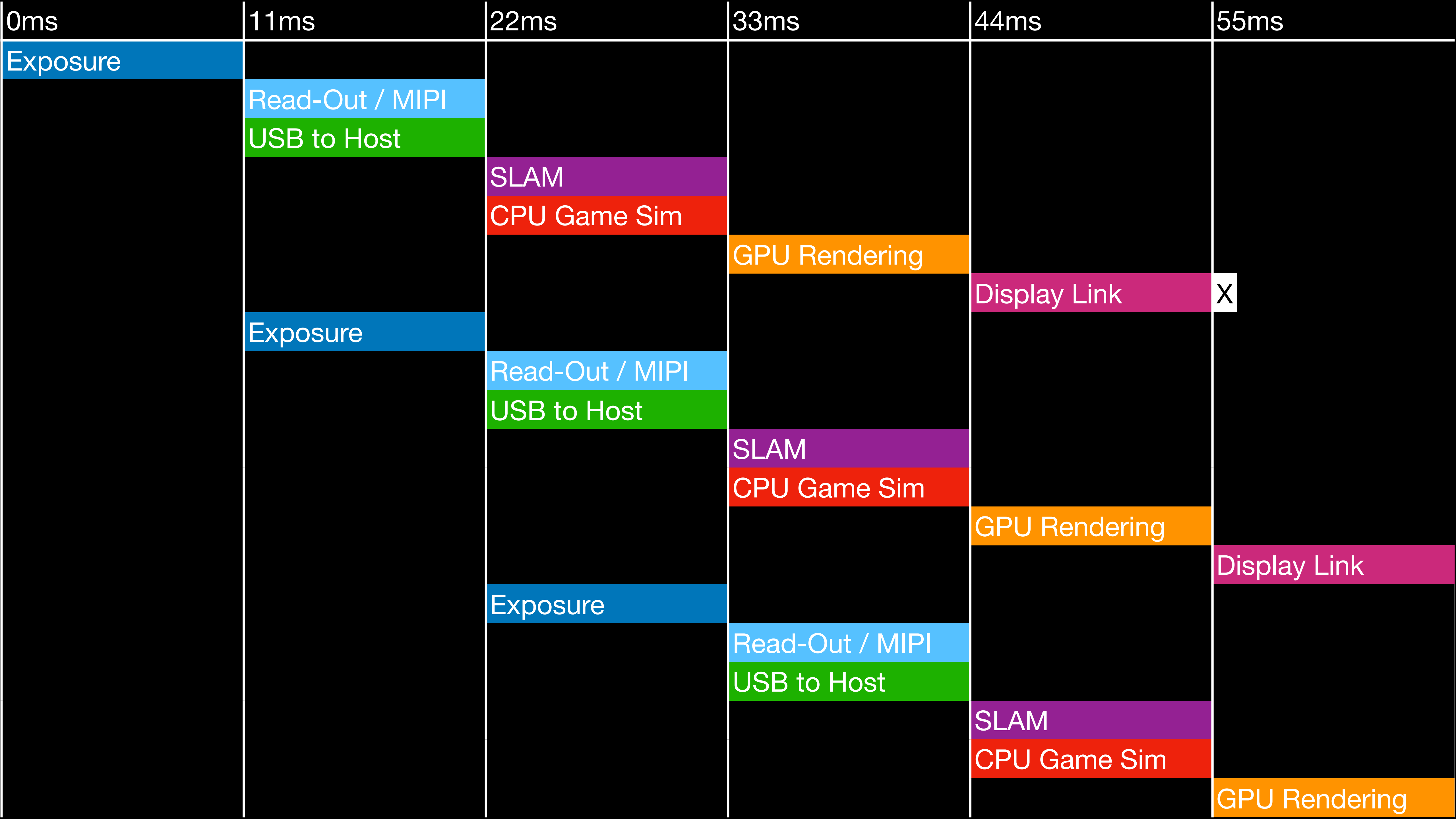


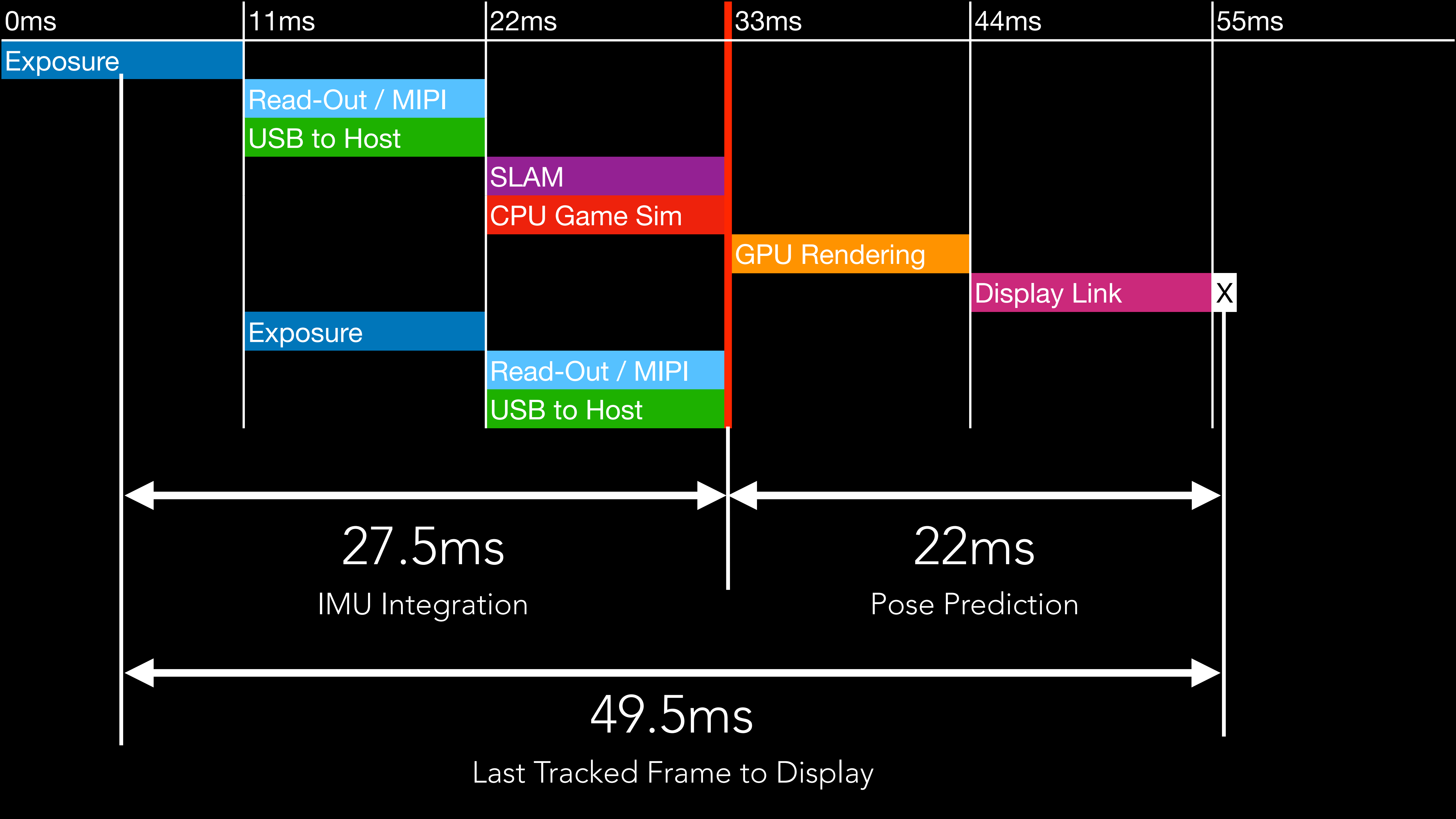
Tracking
 - 90 FPS
 - Requires Full Frame

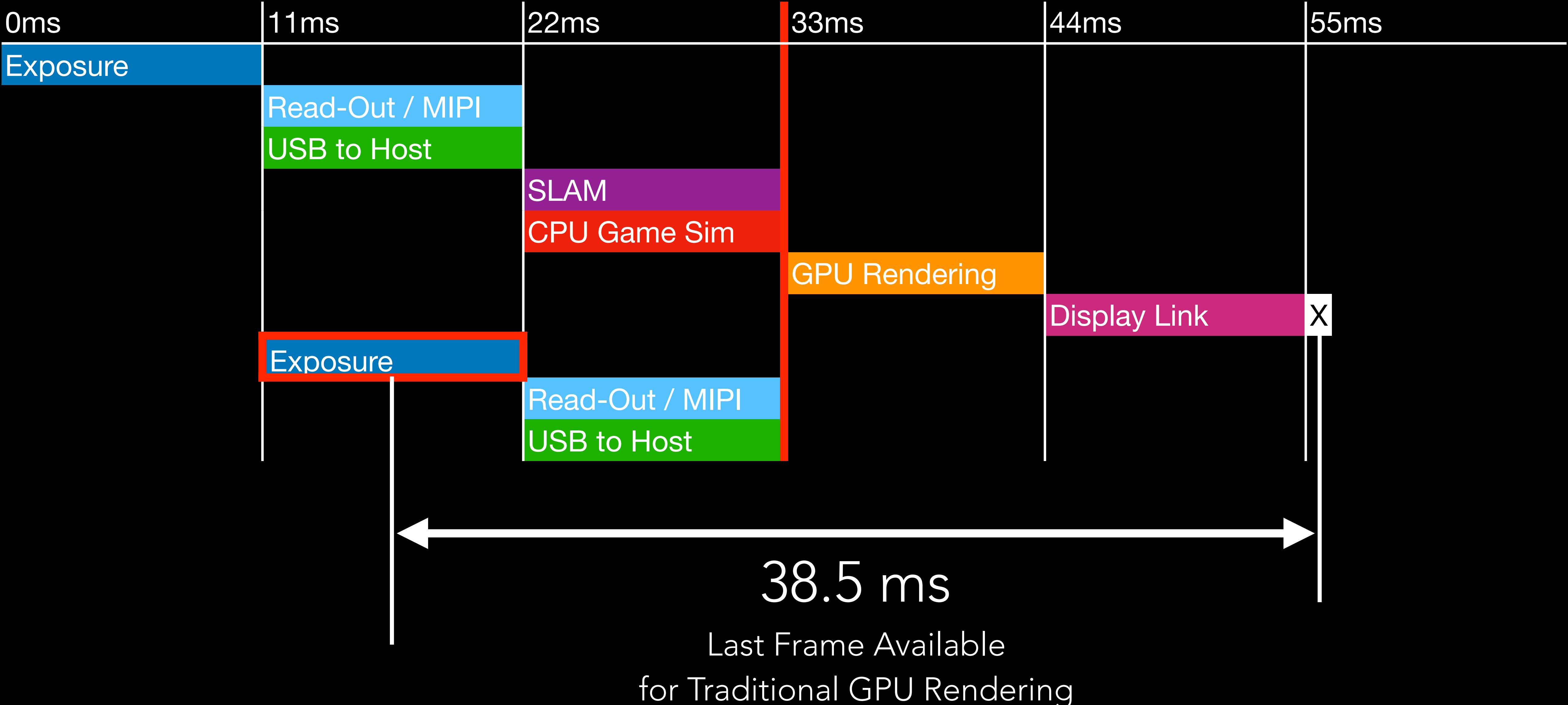


Game / Rendering

- Game Simulation
- Rendering
- Display Link

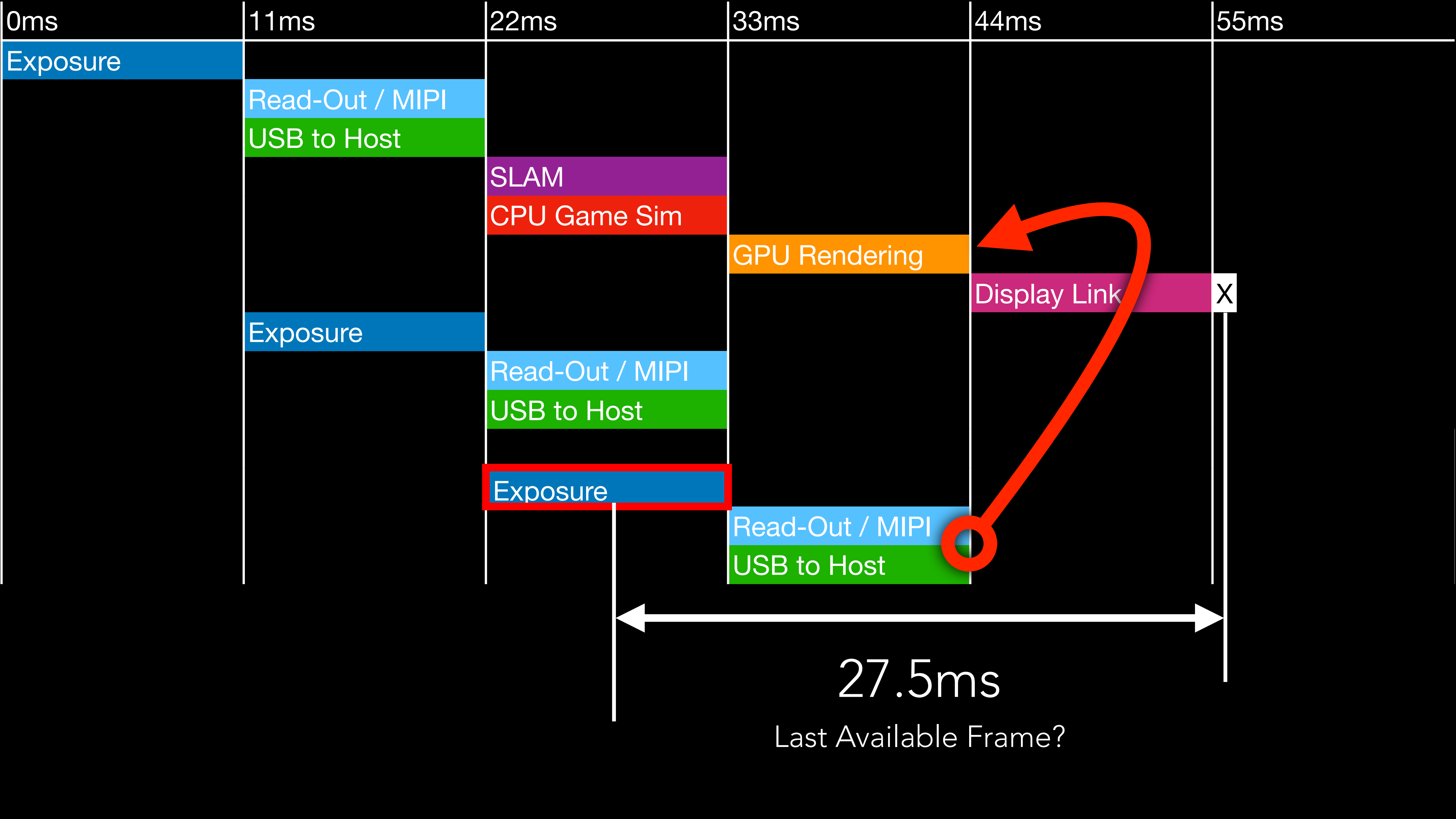






38.5 ms

Last Frame Available
for Traditional GPU Rendering



Improvements

Temporal, Geometric, & Photometric "Wish List"

TEMPORAL IMPROVEMENTS

- **Anything that shortens the system latency timing diagram.**
- Faster cameras (270+ FPS)
 - Improved QE, Read Noise, Fast Lenses, ...
- Manipulated Readout Order for Global Shutter Cameras
 - Deliver downsampled image first / fast, then follow up with remainder
- Higher Bandwidths - Display Link, Camera Interfaces

GEOMETRIC IMPROVEMENTS

- Perturbation-Tolerant SLAM & Calibration Systems
 - Impact / Mechanical Strain
 - Thermal Effects
- Models for Floating Auto-Focus Lenses
 - (especially future high-resolution systems)

PHOTOMETRIC IMPROVEMENTS

- Photorealism for Mixed Reality Compositing
 - Minimized read noise
 - Very high dynamic range (in single exposures)
- Synchronized & Offloaded to Sensor IC:
 - Auto-Exposure / Auto-Gain
 - Color balance

Maintain the cost, size, weight, and power of current fixed-focus embedded cameras.



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