

Dual Structured Light 3D Using a 1D Sensor

Jian Wang Aswin Sankaranarayanan Srinivasa Narasimhan

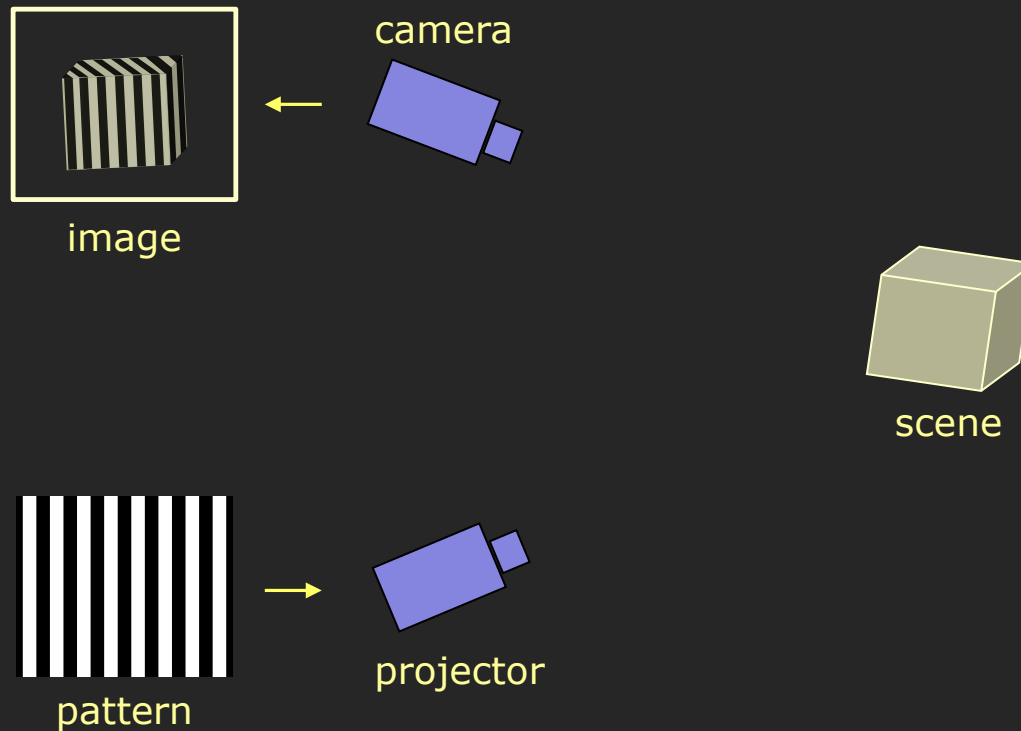
Carnegie Mellon University

Mohit Gupta

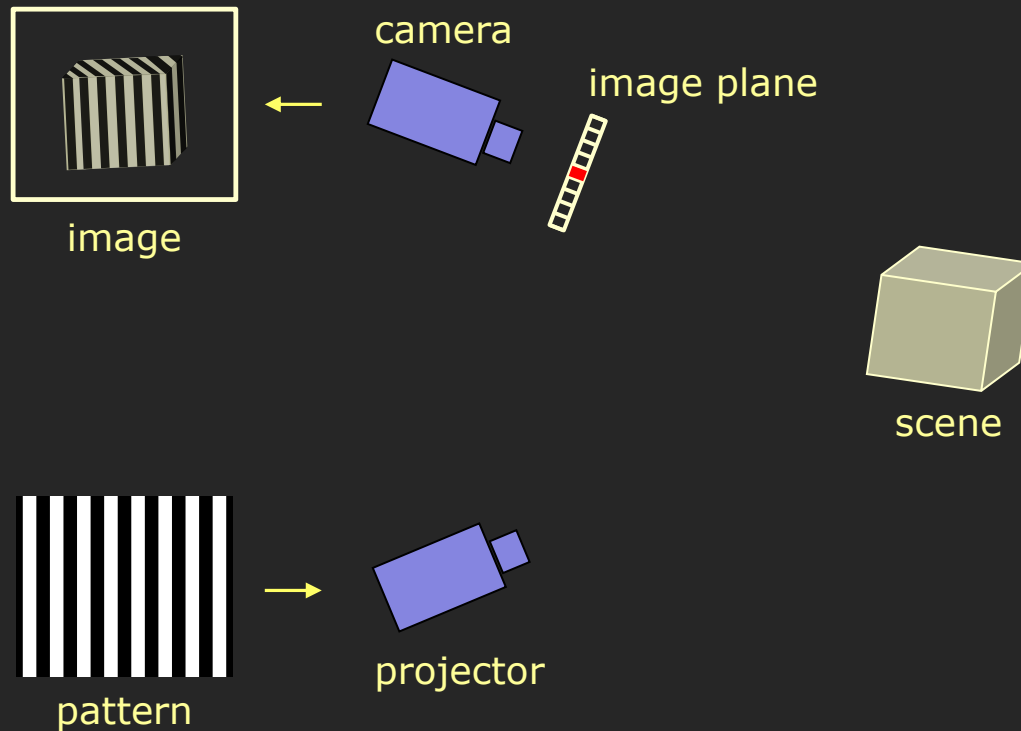
University of Wisconsin-Madison

Support: ONR, DARPA, NSF

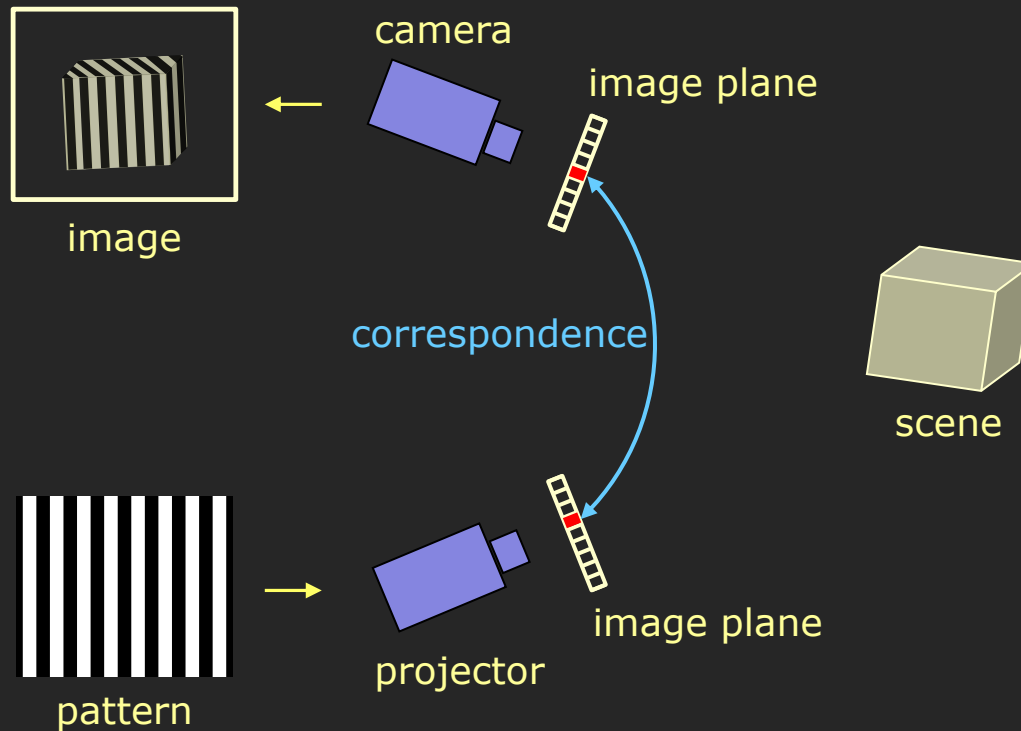
Shape from Structured Light



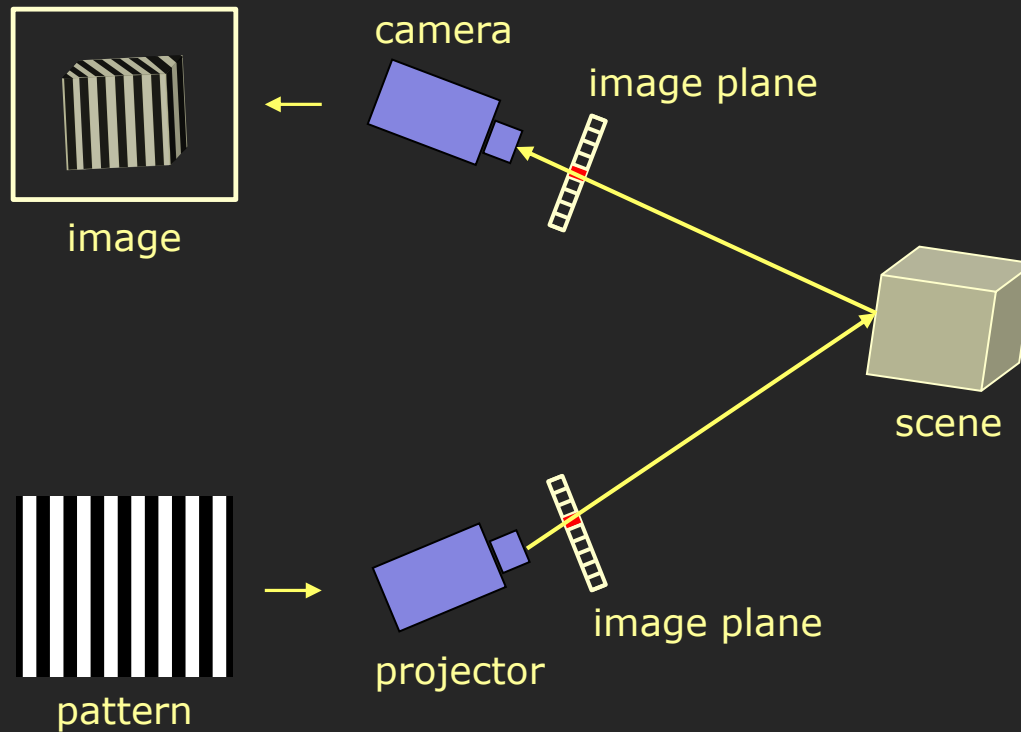
Shape from Structured Light



Shape from Structured Light



Shape from Structured Light



Modern 3D Cameras



Microsoft
Kinect



Projected pattern on scene



Depth map

Modern 3D Cameras



Microsoft
Kinect



Projected pattern on scene



Depth map

Potential to Revolutionize Diverse Application Domains

3D Revolution



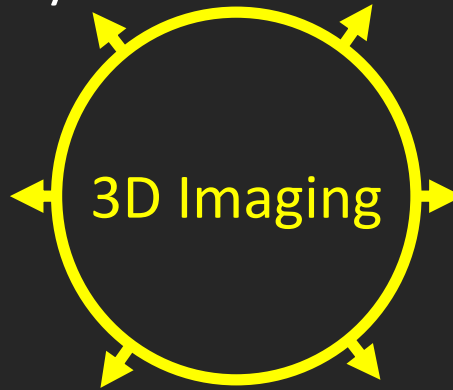
augmented reality



robotic surgery

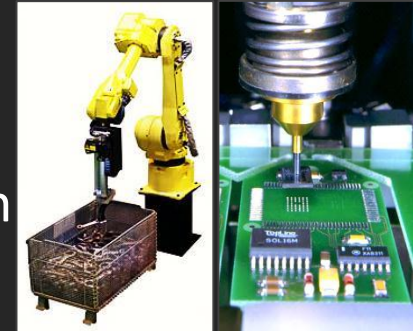


underwater exploration



3D Imaging

industrial automation

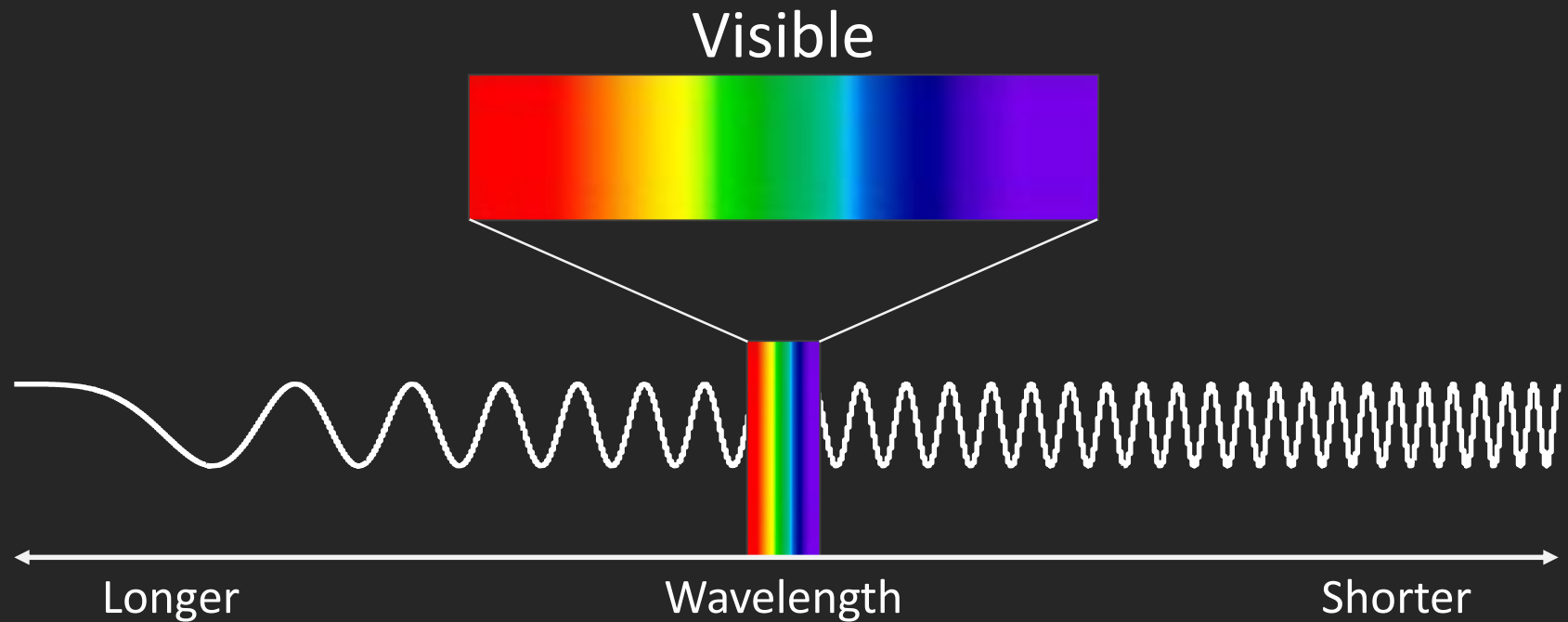


autonomous cars

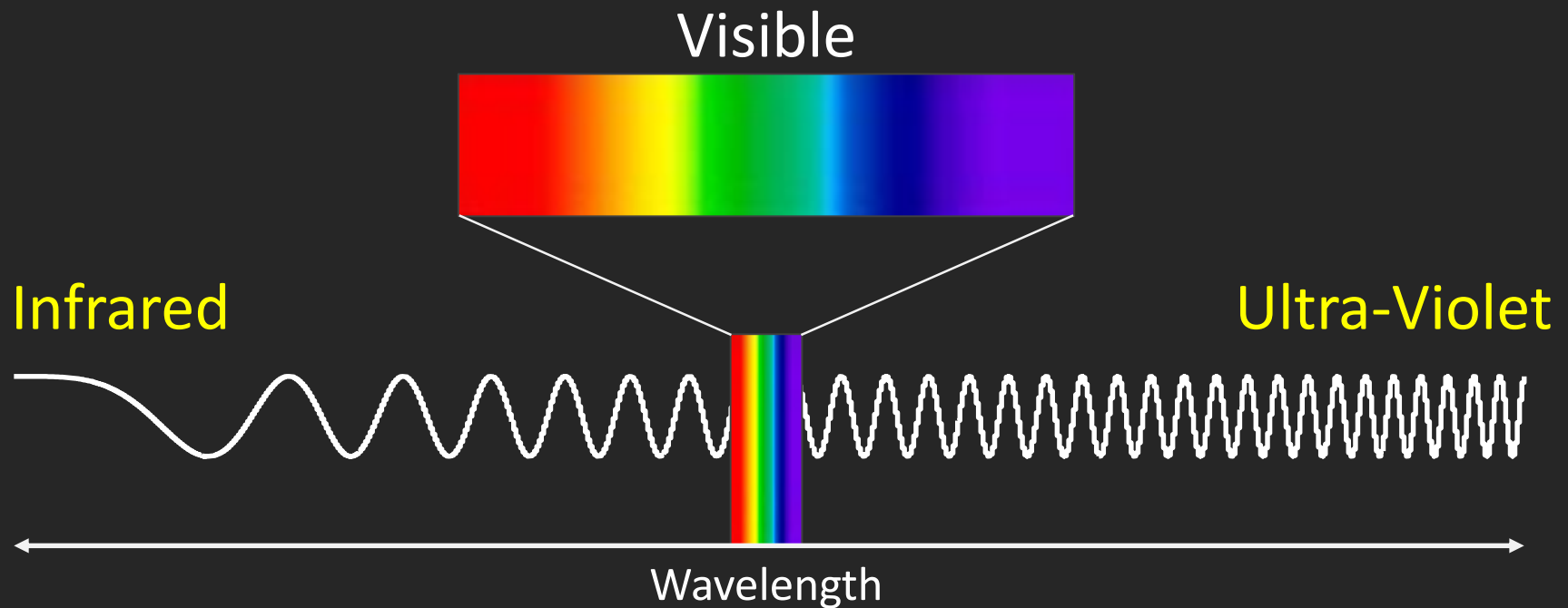
exploratory robots



Structured Light Outside Visible Spectrum



Structured Light Outside Visible Spectrum



Can We Build Structured Light Systems Outside Visible?

Imaging in Short-Wave InfraRed (SWIR)

Visible Wavelengths (400-700 nm)



Imaging in Short-Wave InfraRed (SWIR)

Visible Wavelengths (400-700 nm)



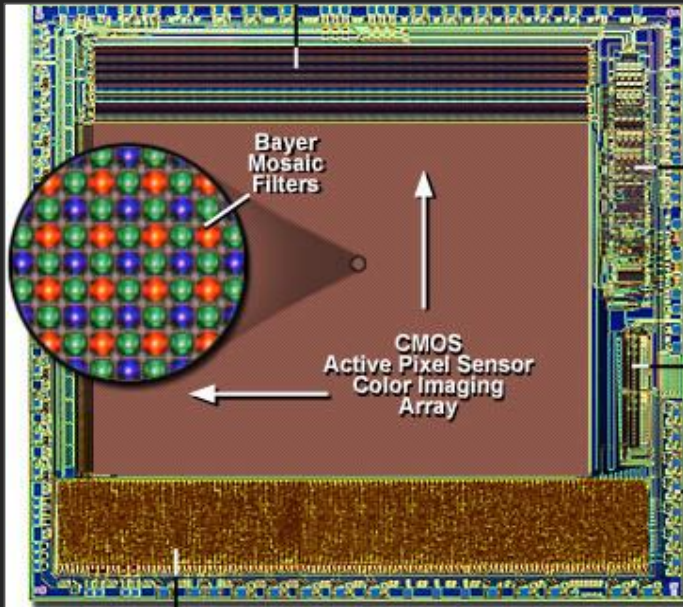
SWIR Wavelengths (1500-2500nm)



Strong Ability to See Through Scattering Media (Haze, Smoke)

Cost of Visible vs. SWIR Sensors

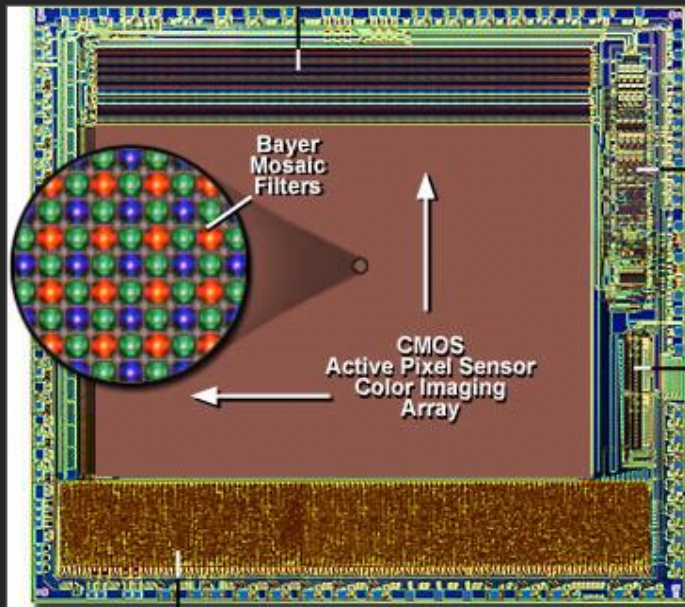
Visible CMOS Sensor (Silicon)



0.0001 cents per pixel

Cost of Visible vs. SWIR Sensors

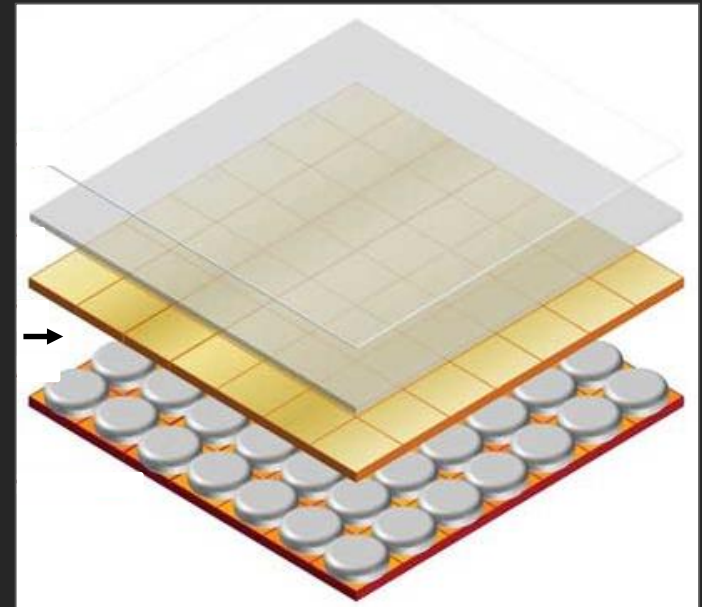
Visible CMOS Sensor
(Silicon)



0.0001 cents per pixel

SWIR Sensor
(Indium-Gallium-Arsenide)

InGaAs
Array



10 cents per pixel

High Cost of SWIR Sensors



2D SWIR Camera
Cost: \$100,000

High Cost of SWIR Sensors



2D SWIR Camera
Cost: \$100,000

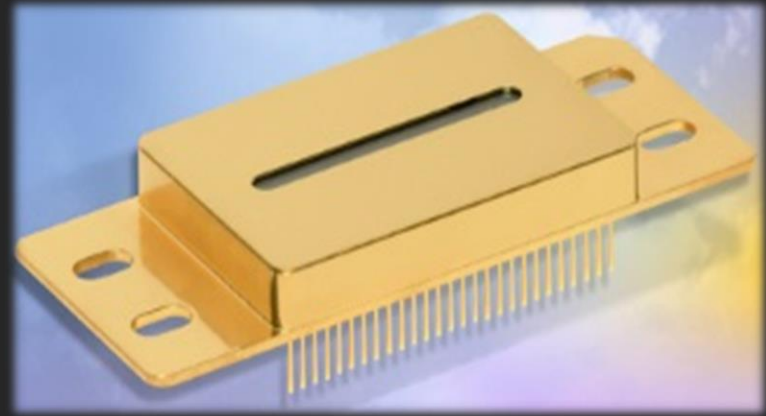


1D SWIR Camera
Cost: \$100

High Cost of SWIR Sensors



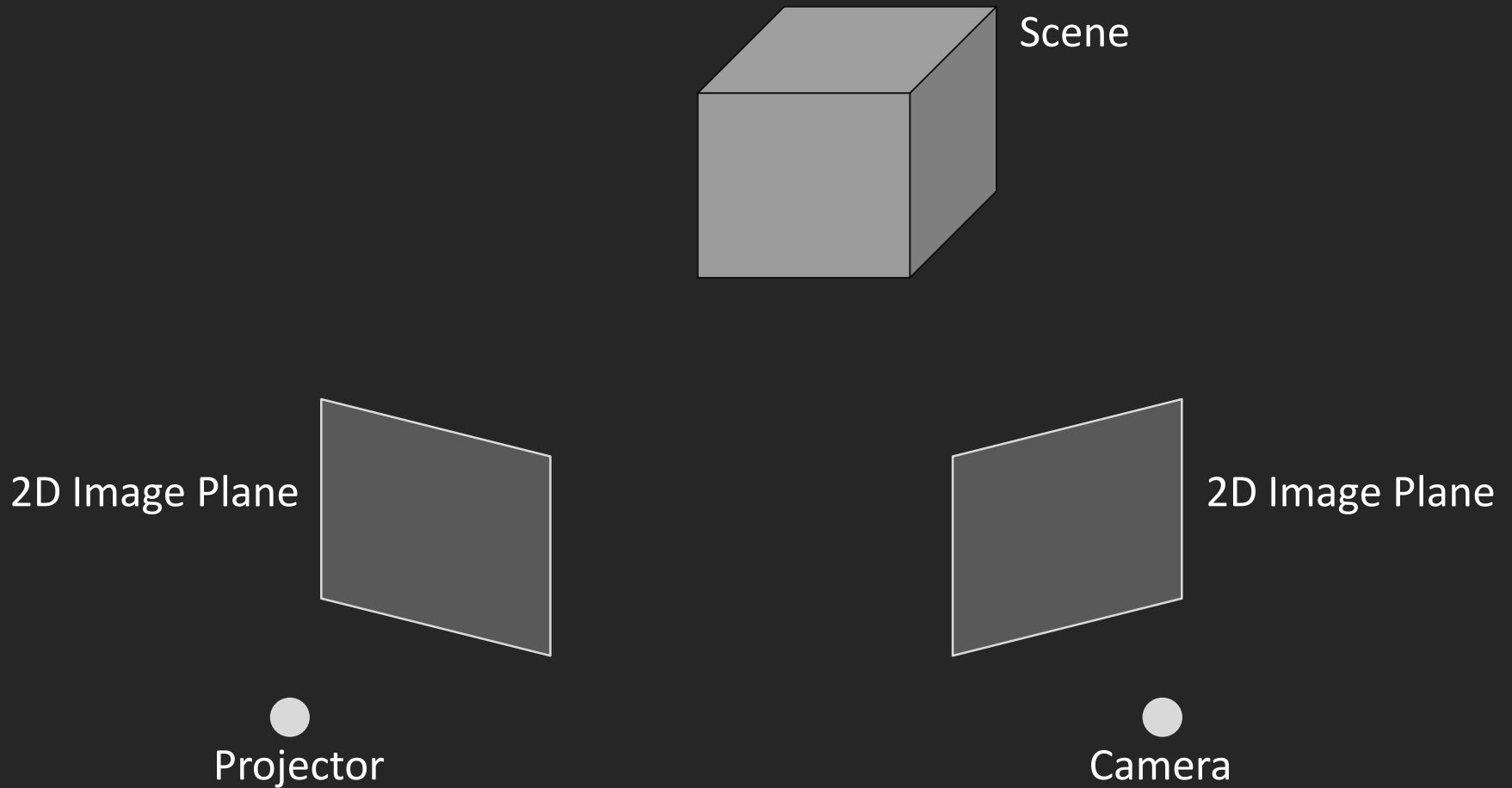
2D SWIR Camera
Cost: \$100,000



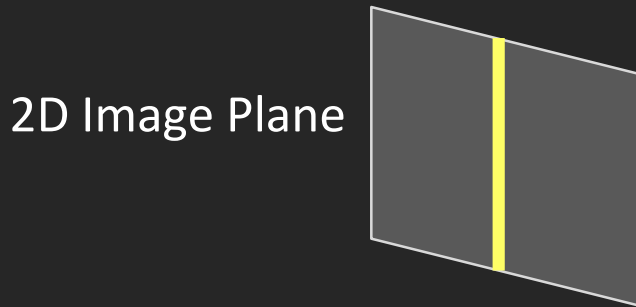
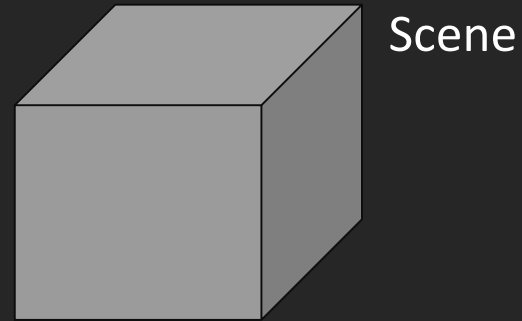
1D SWIR Camera
Cost: \$100

Structured Light 3D Imaging Using 1D Sensor?

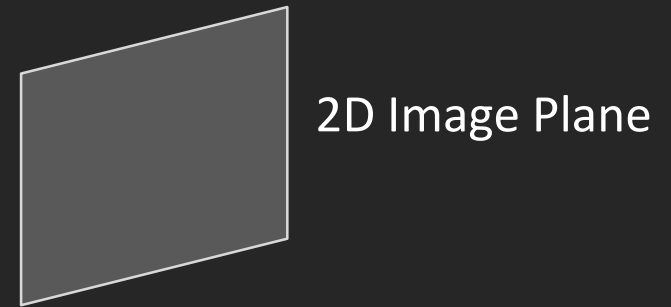
Conventional Structured Light



Conventional Structured Light

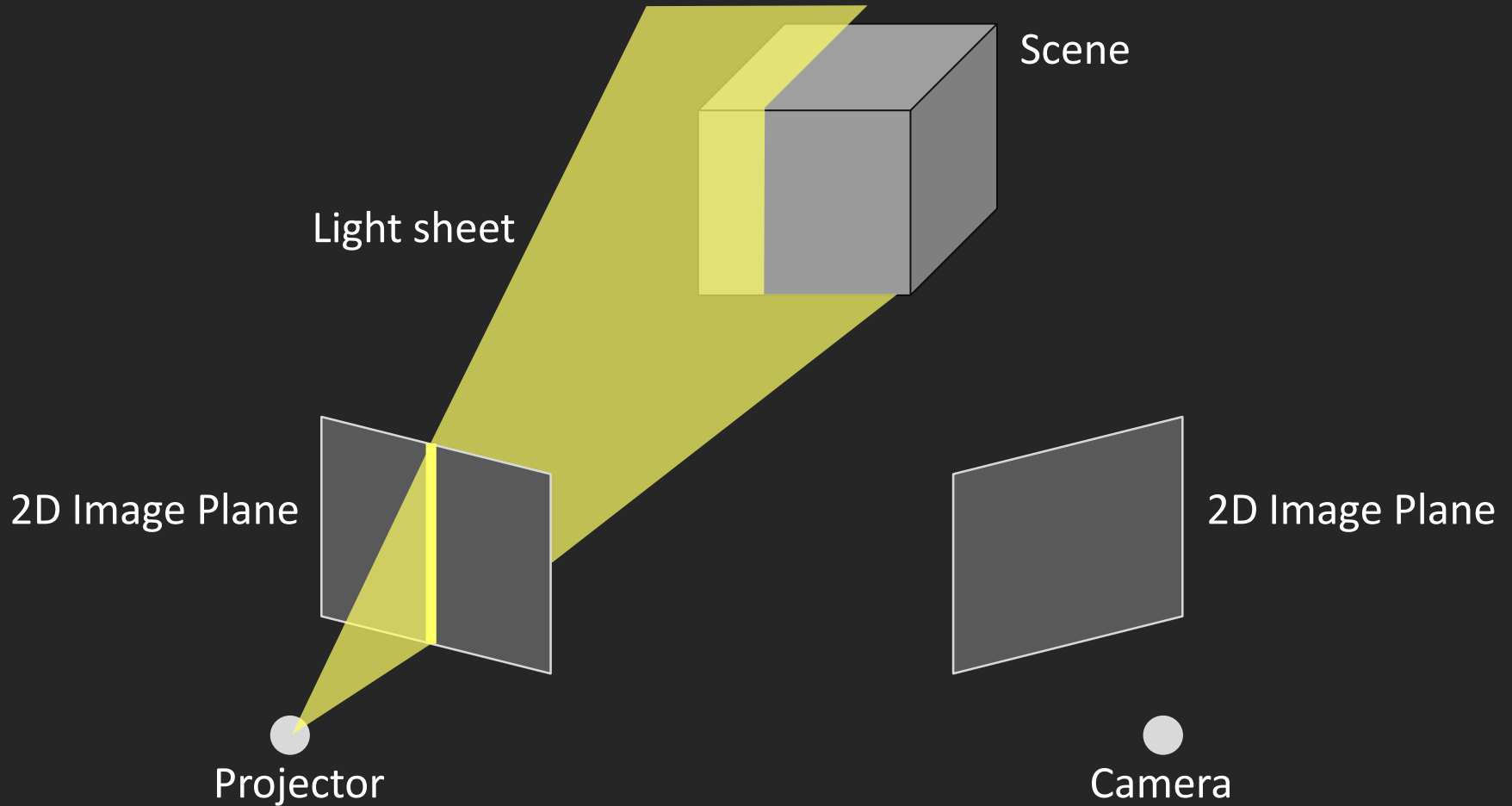


●
Projector

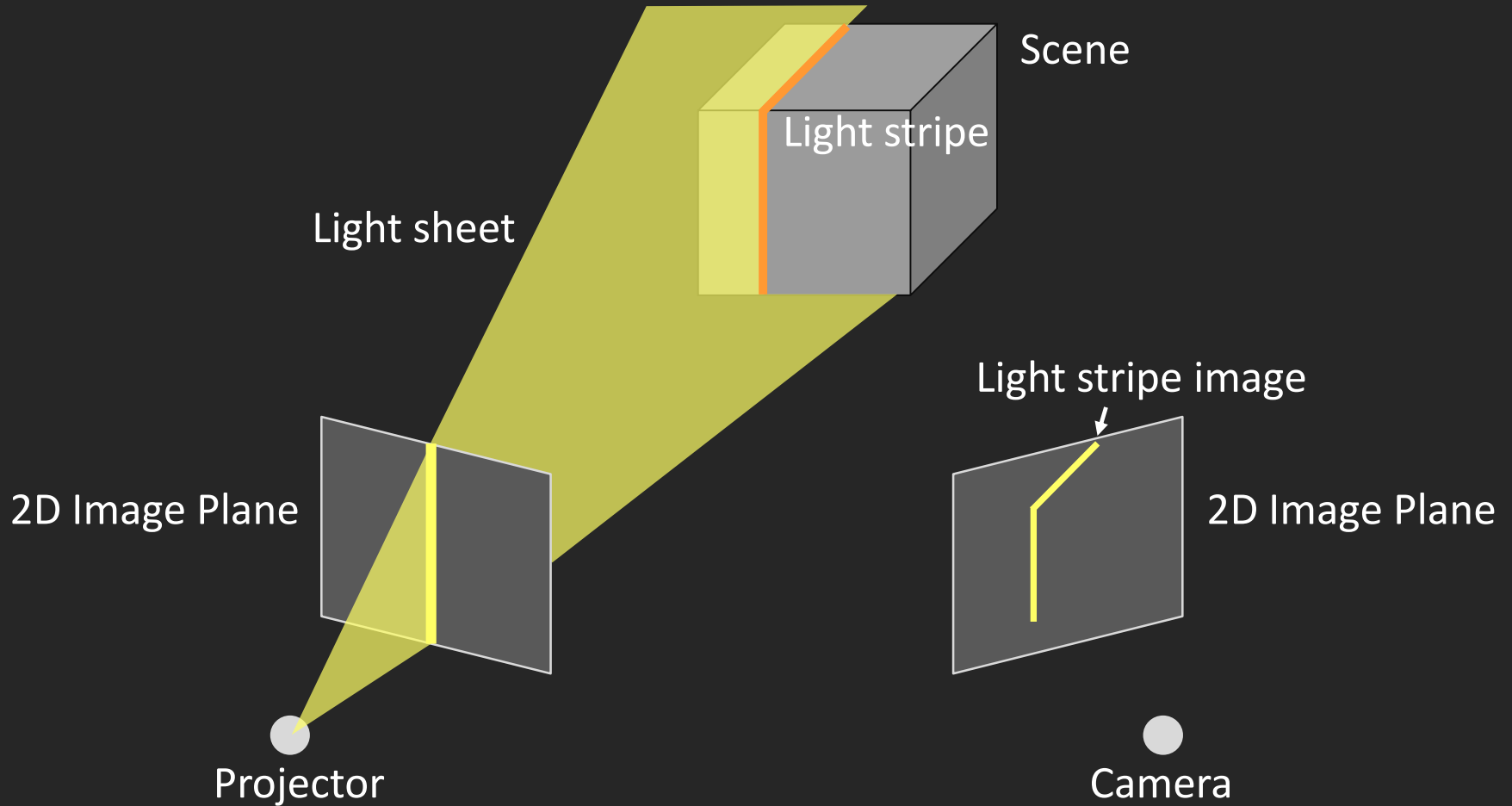


●
Camera

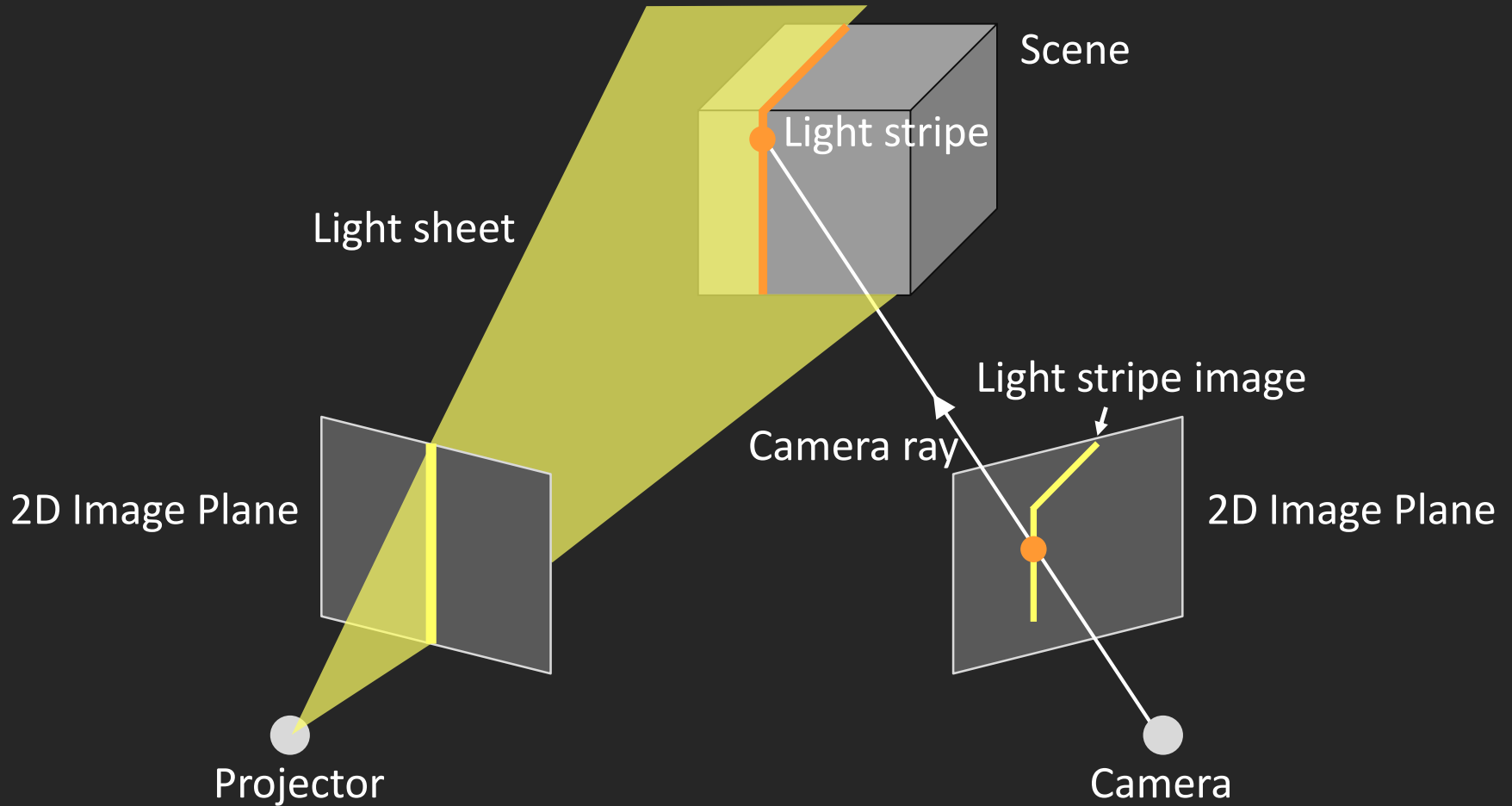
Conventional Structured Light



Conventional Structured Light



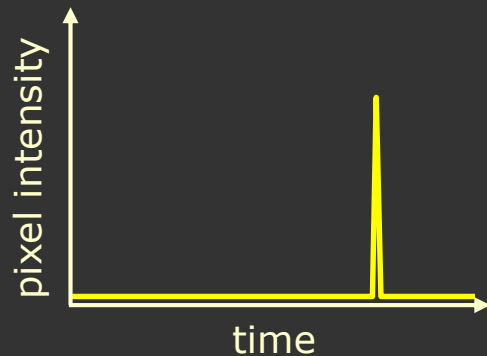
Conventional Structured Light



Triangulation of Camera Ray with Light Sheet

Structured Light Coding Schemes

Projector patterns

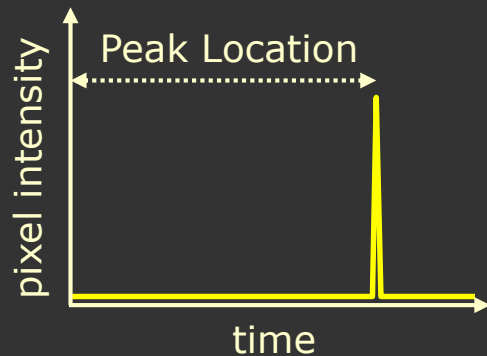
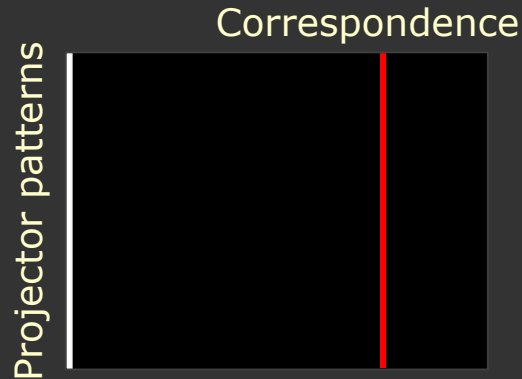


Light Striping

[Shirai and Suwa, 1971]

[Agin and Binford, 1976]

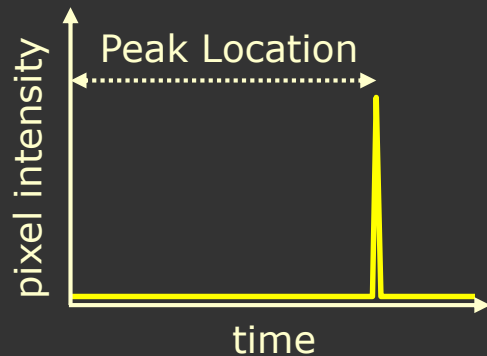
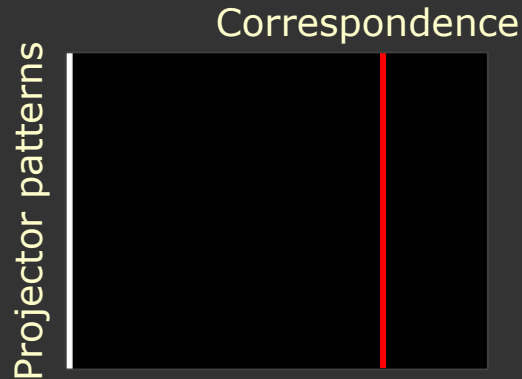
Structured Light Coding Schemes



Light Striping

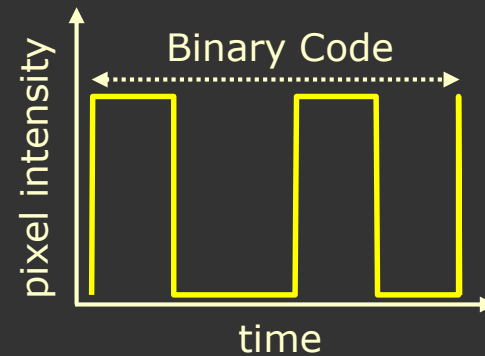
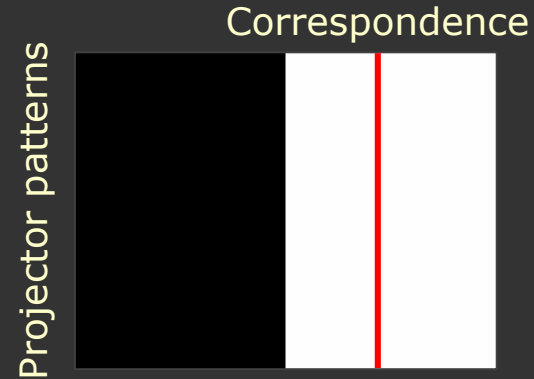
[Shirai and Suwa, 1971]
[Agin and Binford, 1976]

Structured Light Coding Schemes



Light Striping

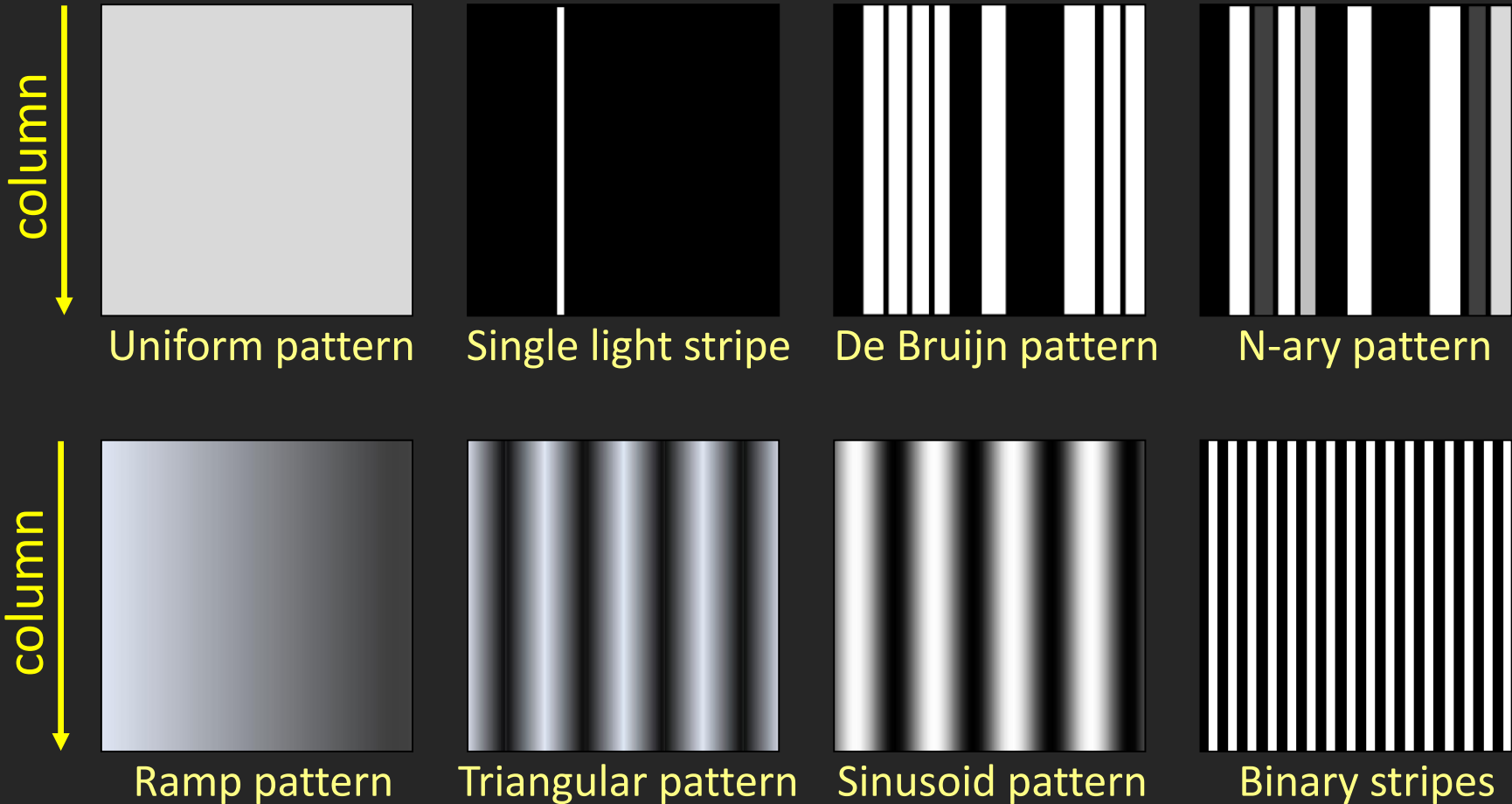
[Shirai and Suwa, 1971]
[Agin and Binford, 1976]



Binary Codes

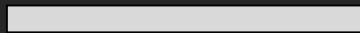
[Minou *et al.*, 1981]
[Posdamer *et al.*, 1982]

Patterns with Translational Symmetry



Patterns with Translational Symmetry

stretch



Uniform pattern



Single light stripe

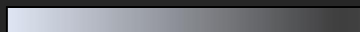


De Bruijn pattern



N-ary pattern

stretch



Ramp pattern



Triangular pattern

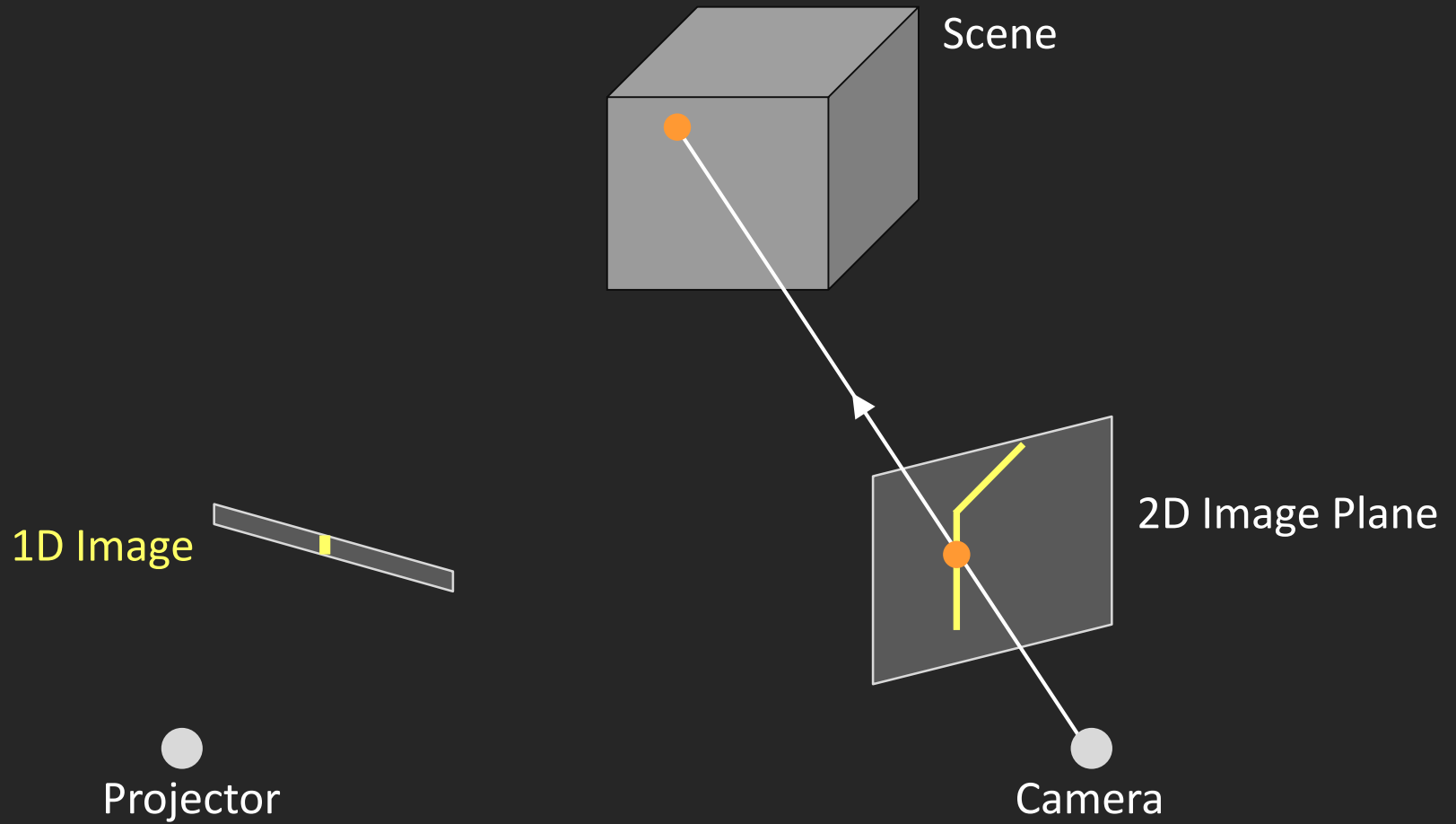


Sinusoid pattern

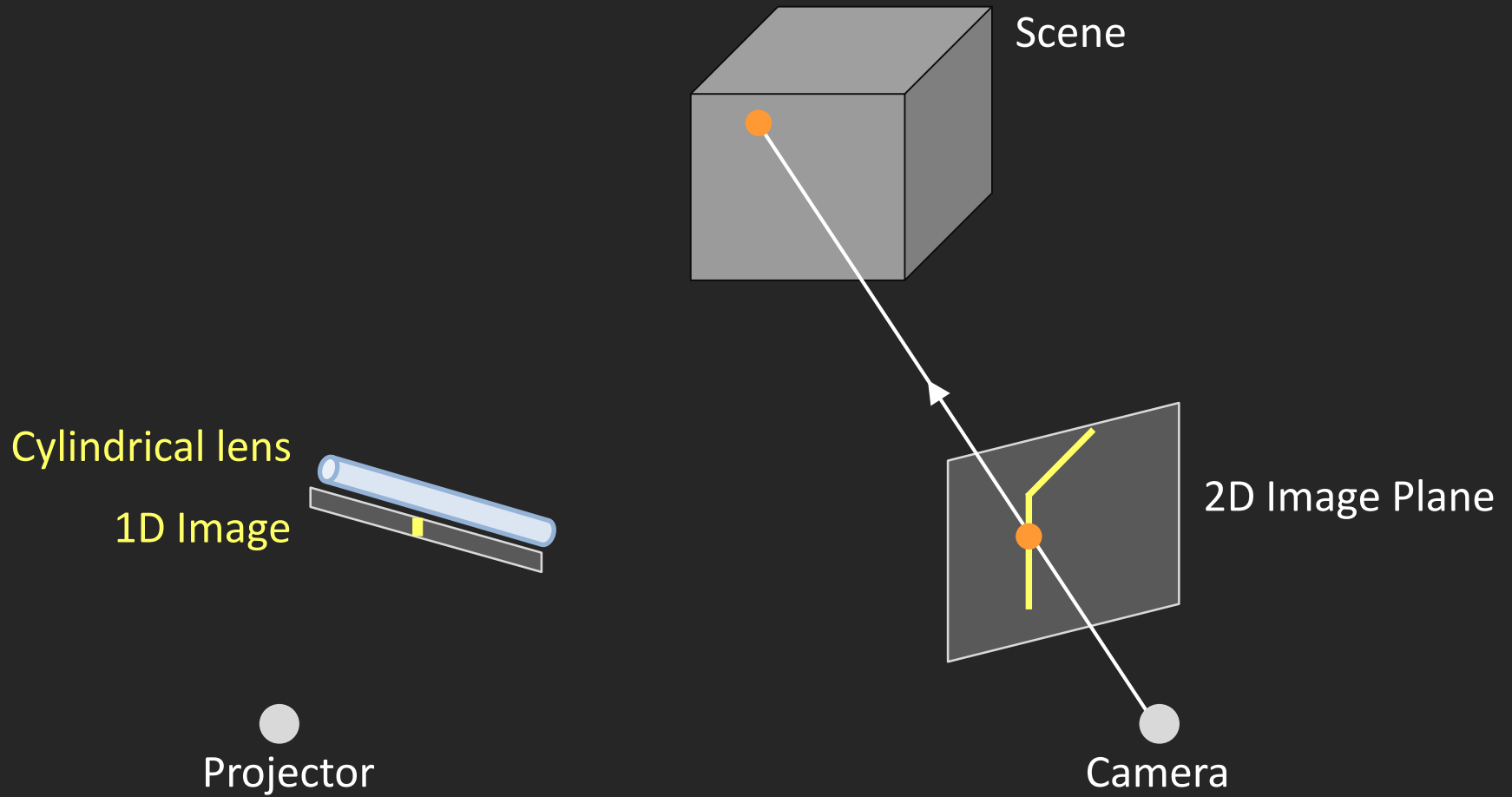


Binary stripes

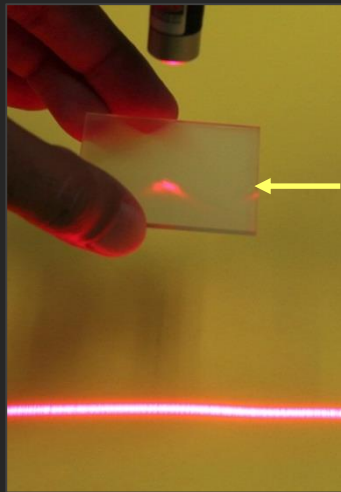
Conceptual 1D Projector



Conceptual 1D Projector

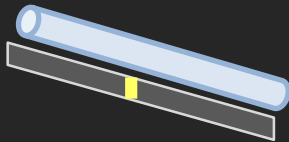


Conceptual 1D Projector

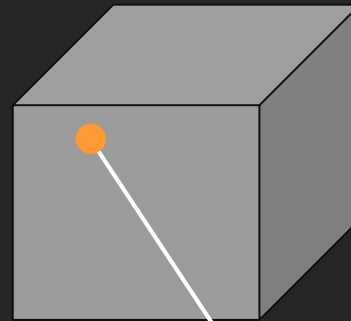


Cylindrical lenses

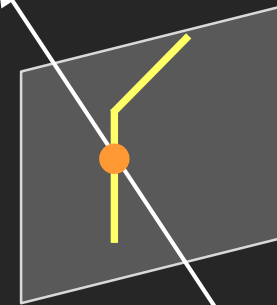
Cylindrical lens
1D Image



●
Projector



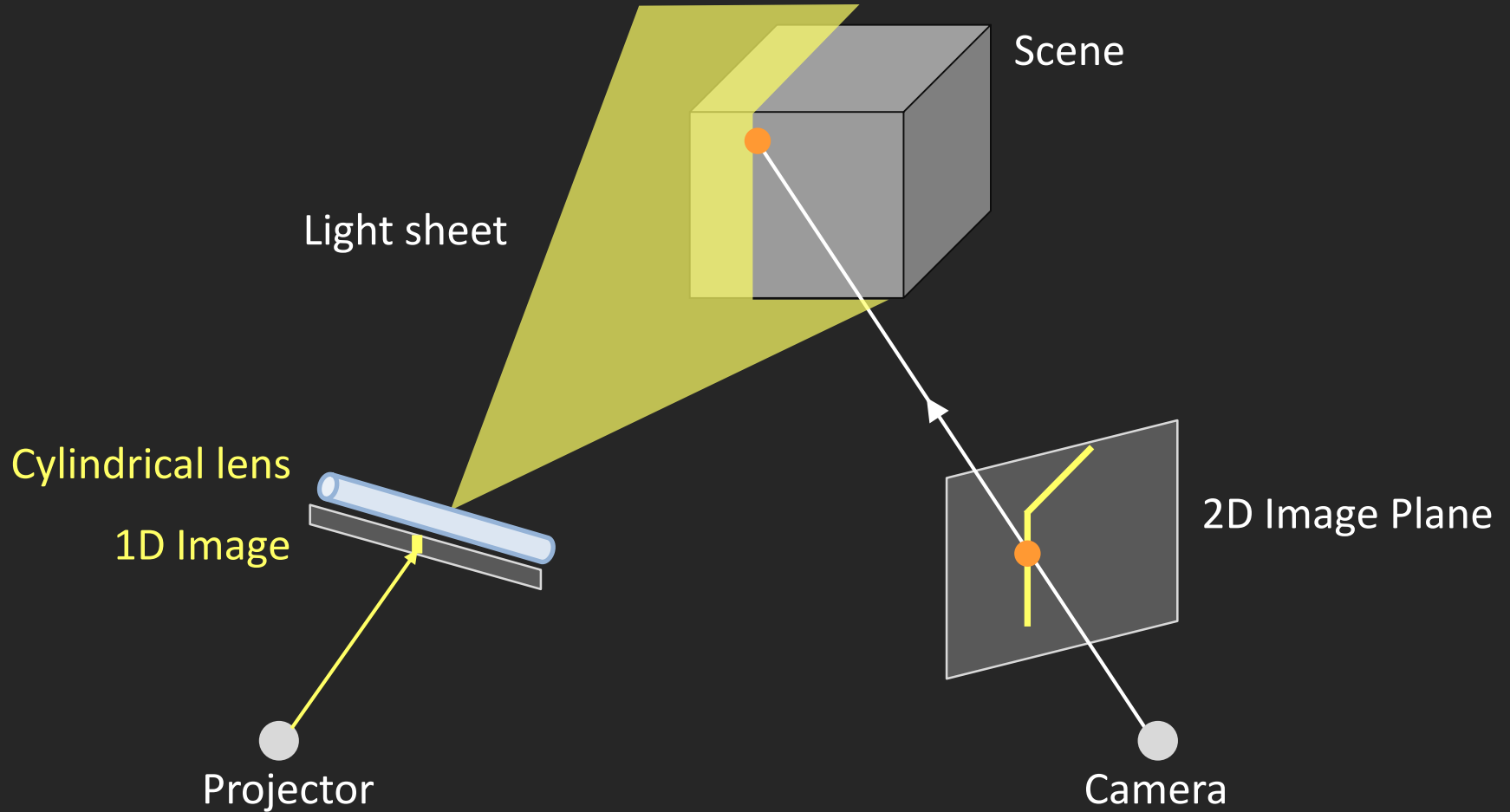
Scene



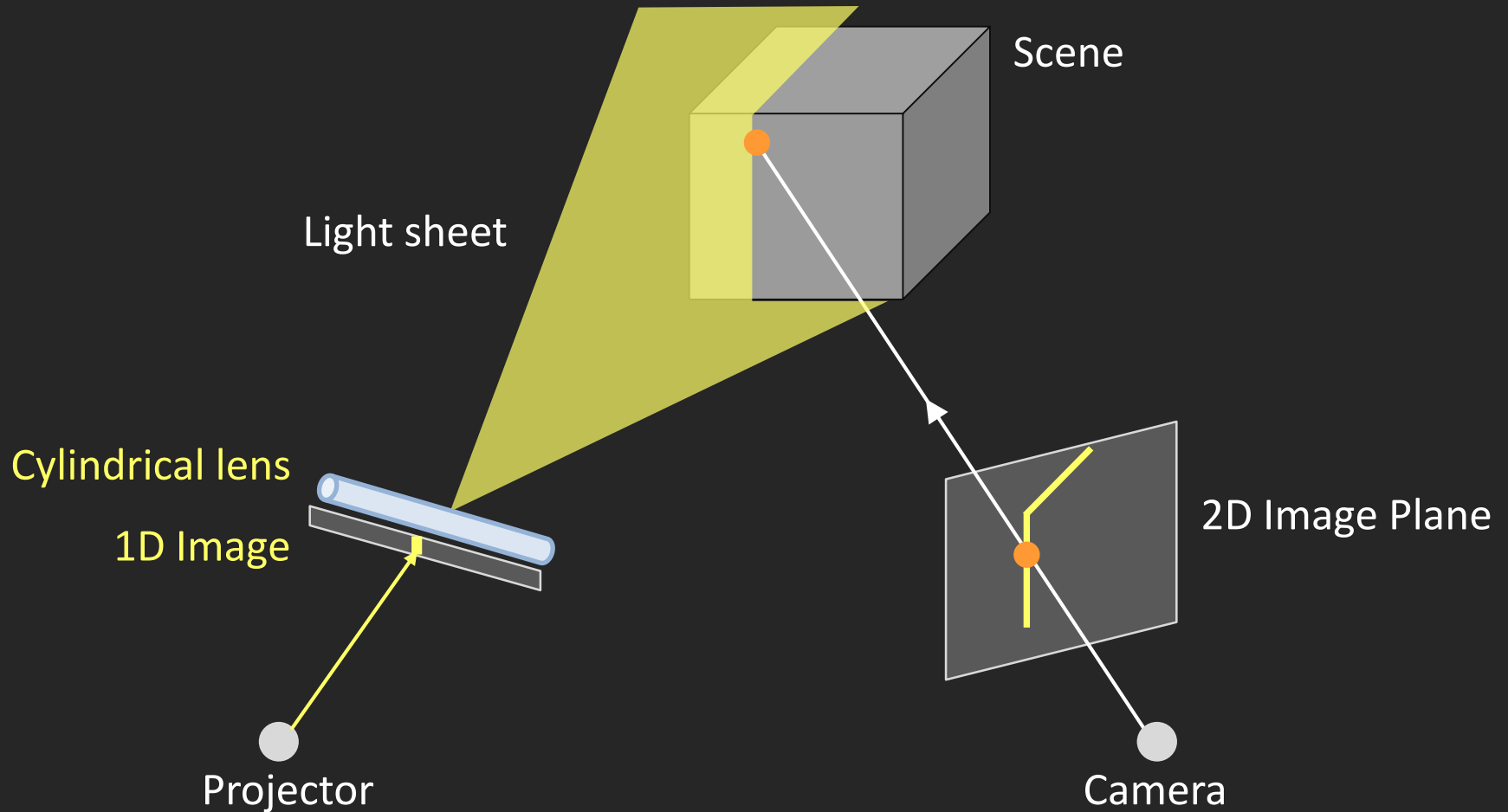
2D Image Plane

●
Camera

Conceptual 1D Projector

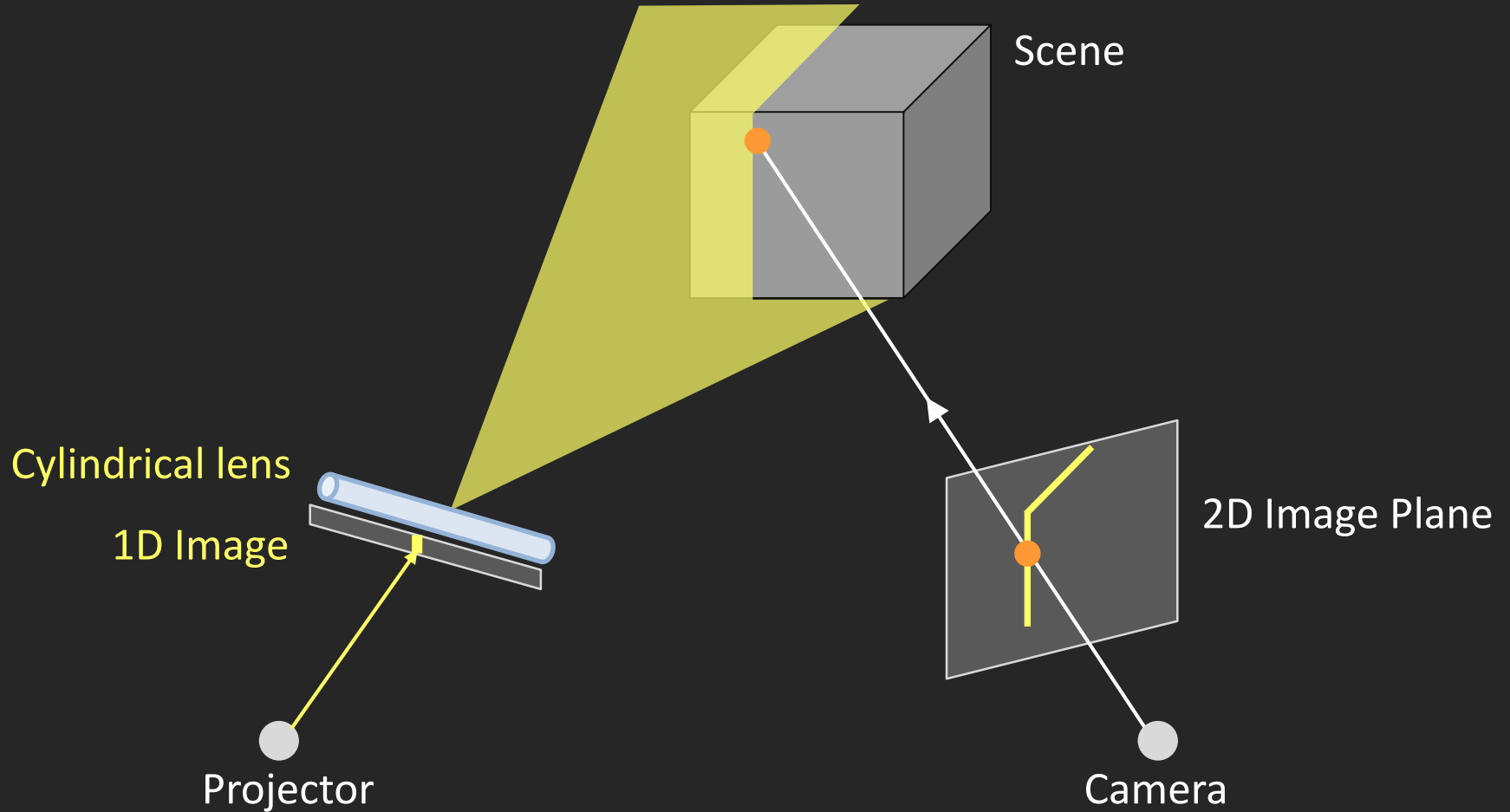


Conceptual 1D Projector

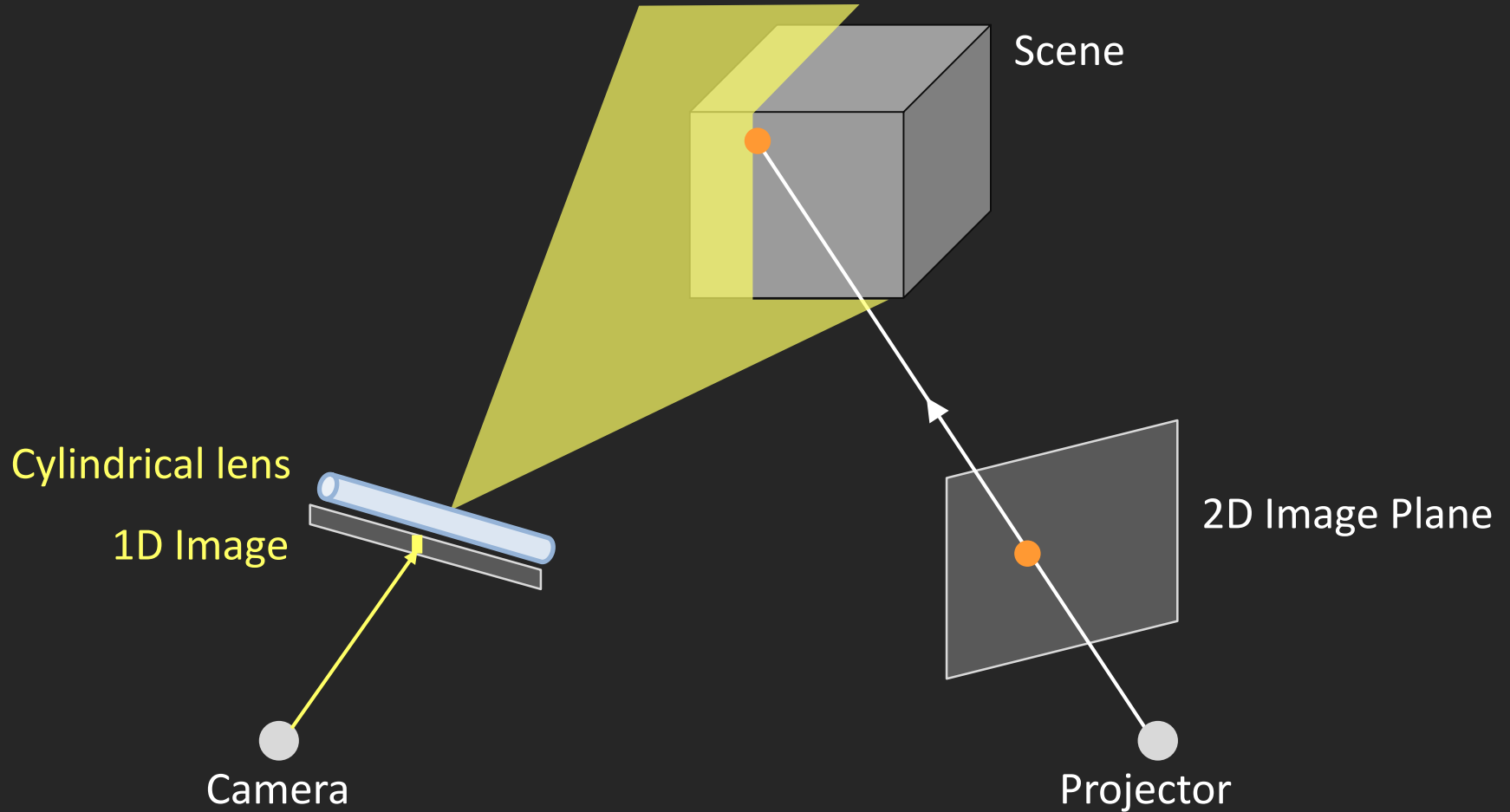


Projector Can be Modeled as Having a 1D Image Plane

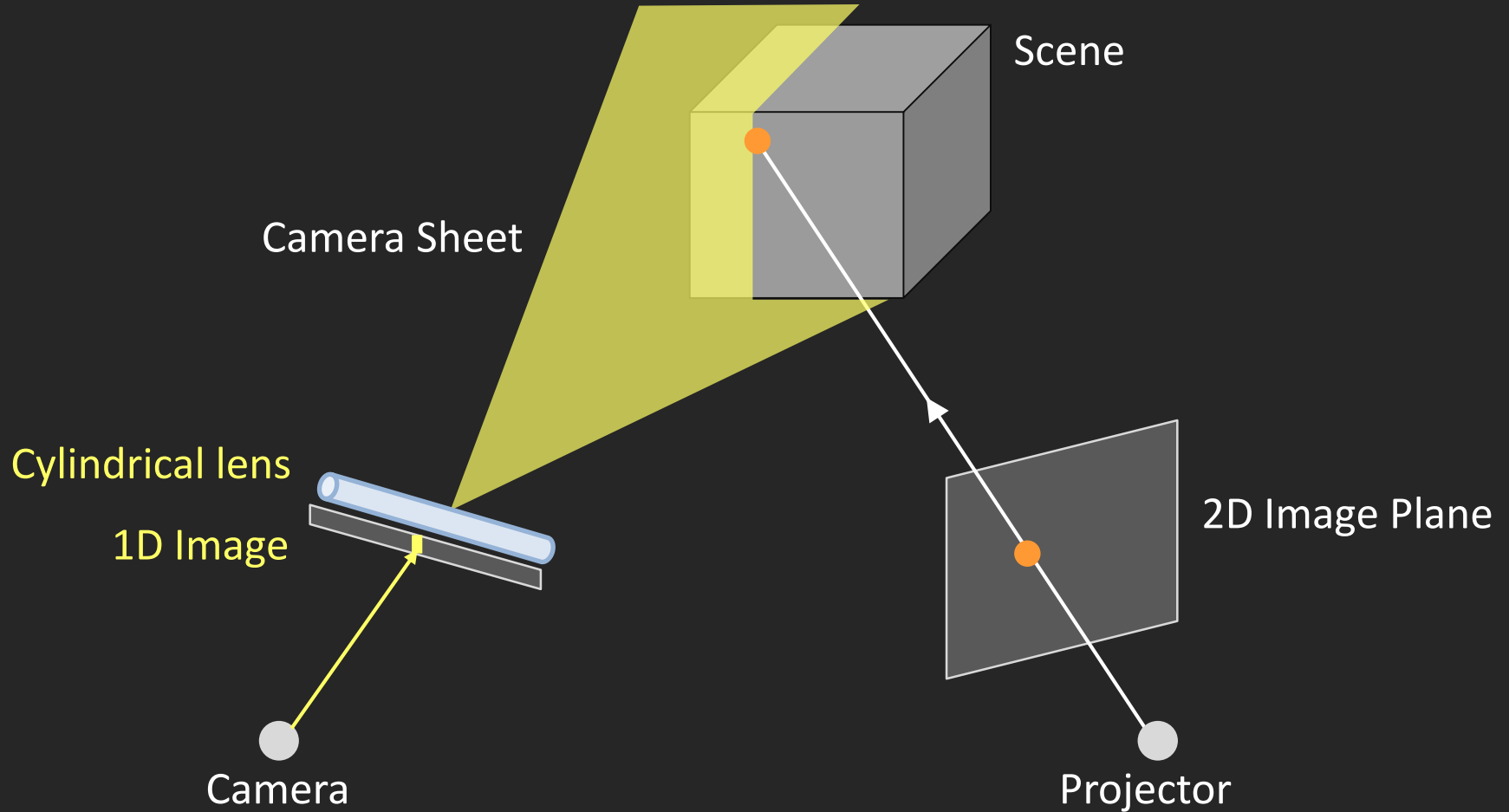
Projector-Camera Duality



Projector-Camera Duality



Projector-Camera Duality



Each Camera Pixel Collects Light Along a Plane

Imaging with Conventional Lens

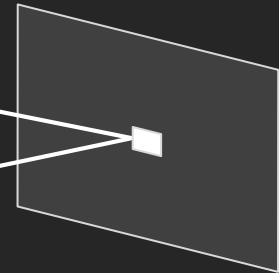
Point PSF



Scene

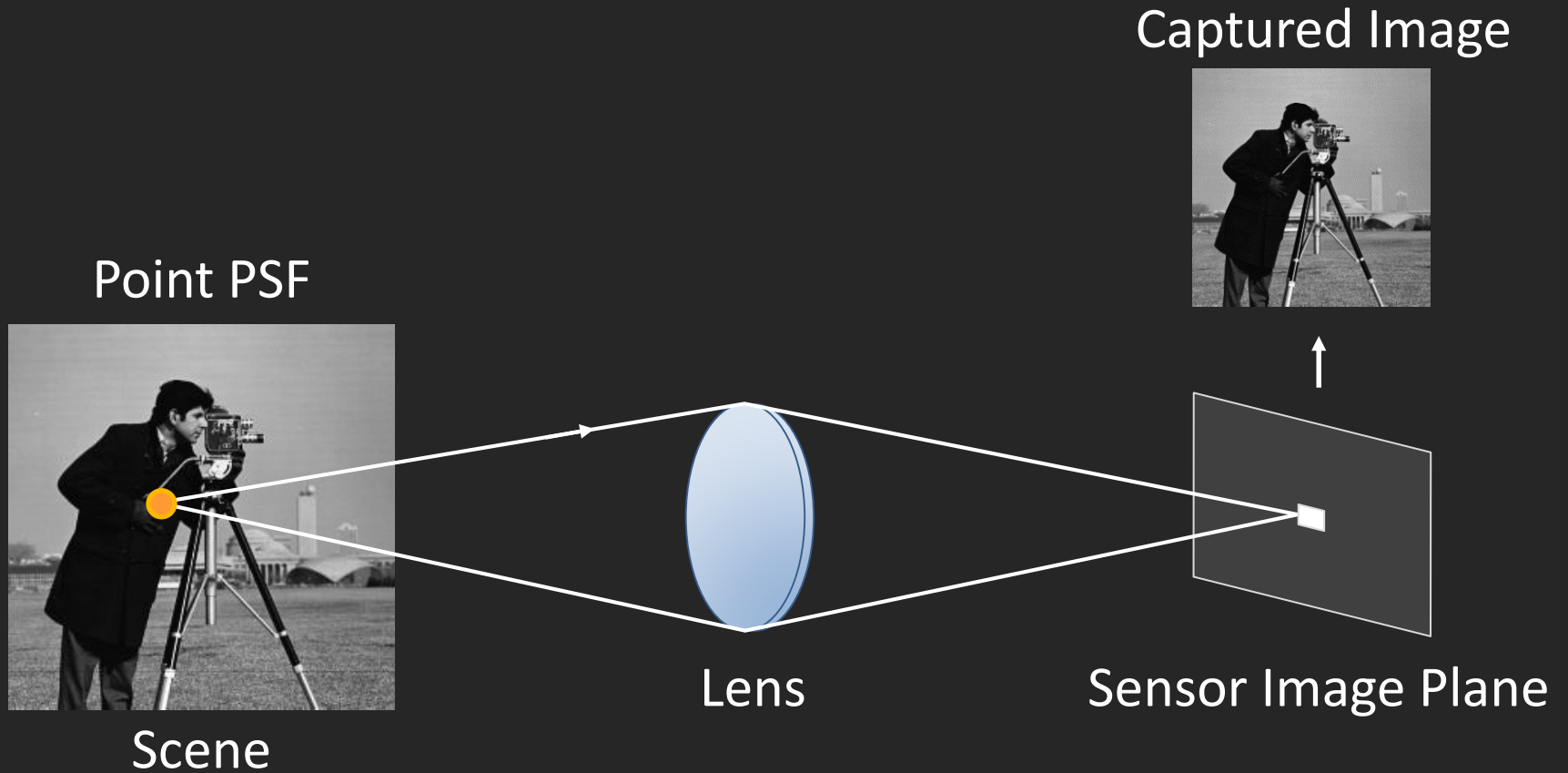


Lens



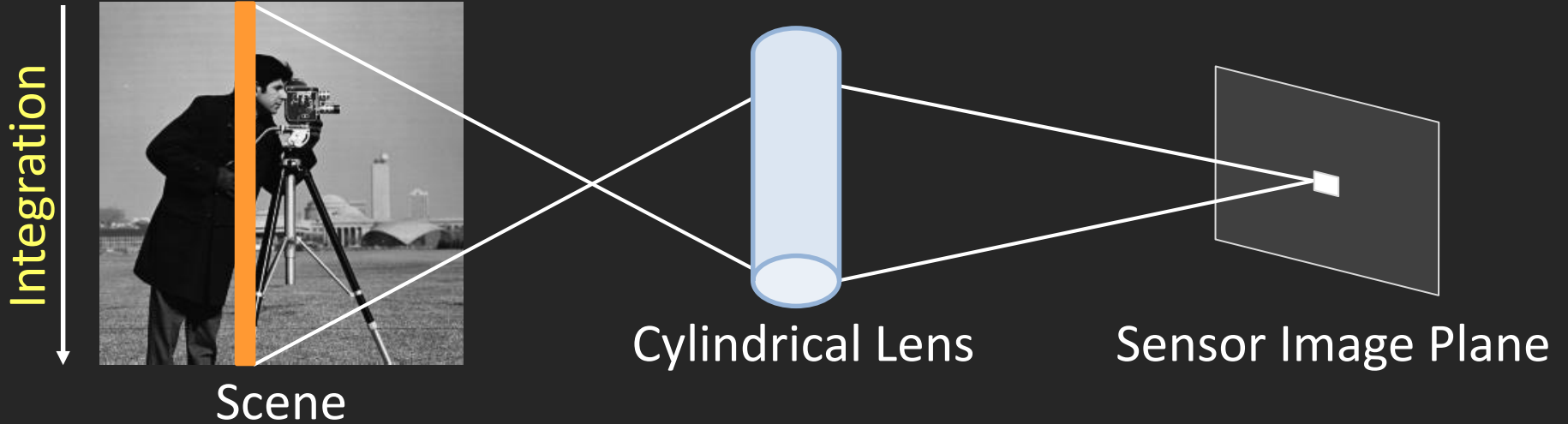
Sensor Image Plane

Imaging with Conventional Lens



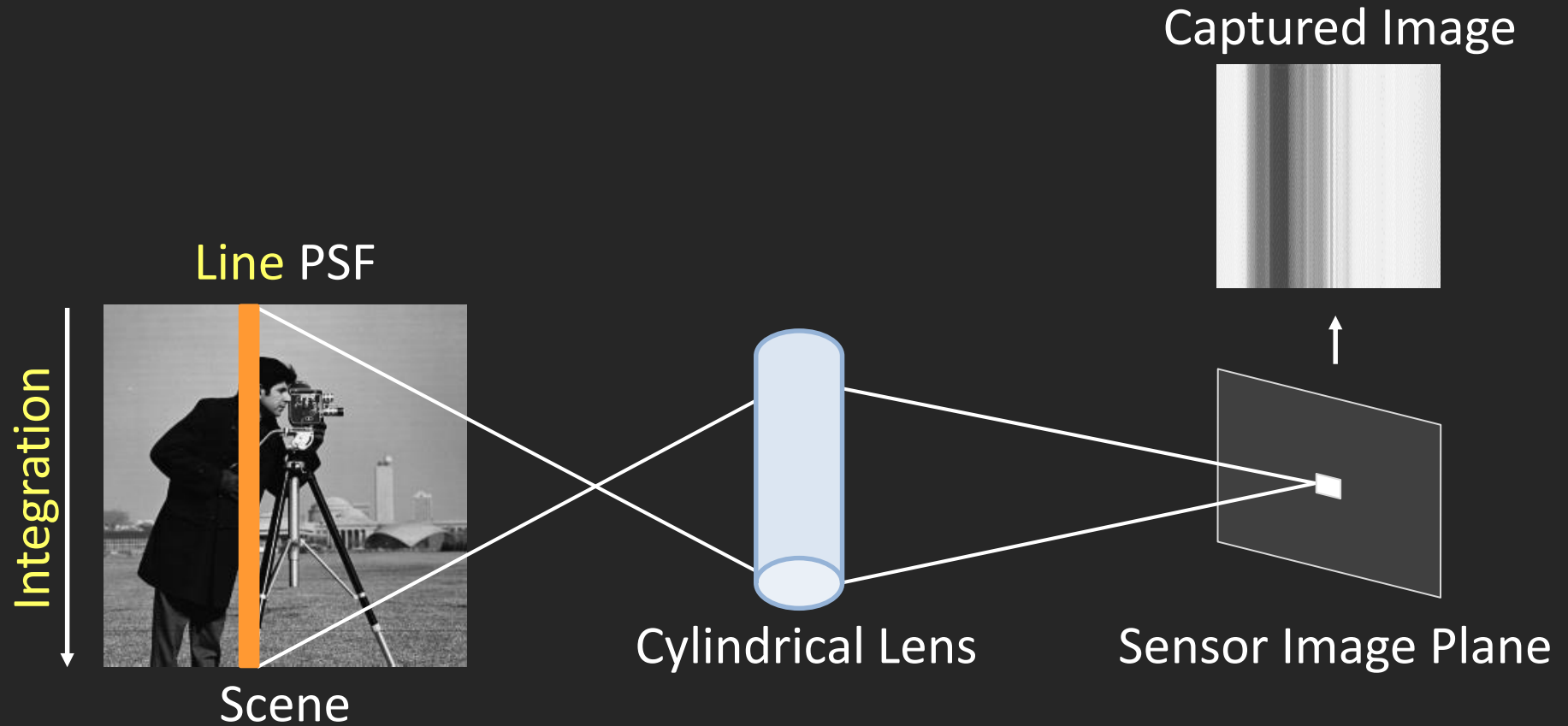
Imaging with Cylindrical Lens

Line PSF



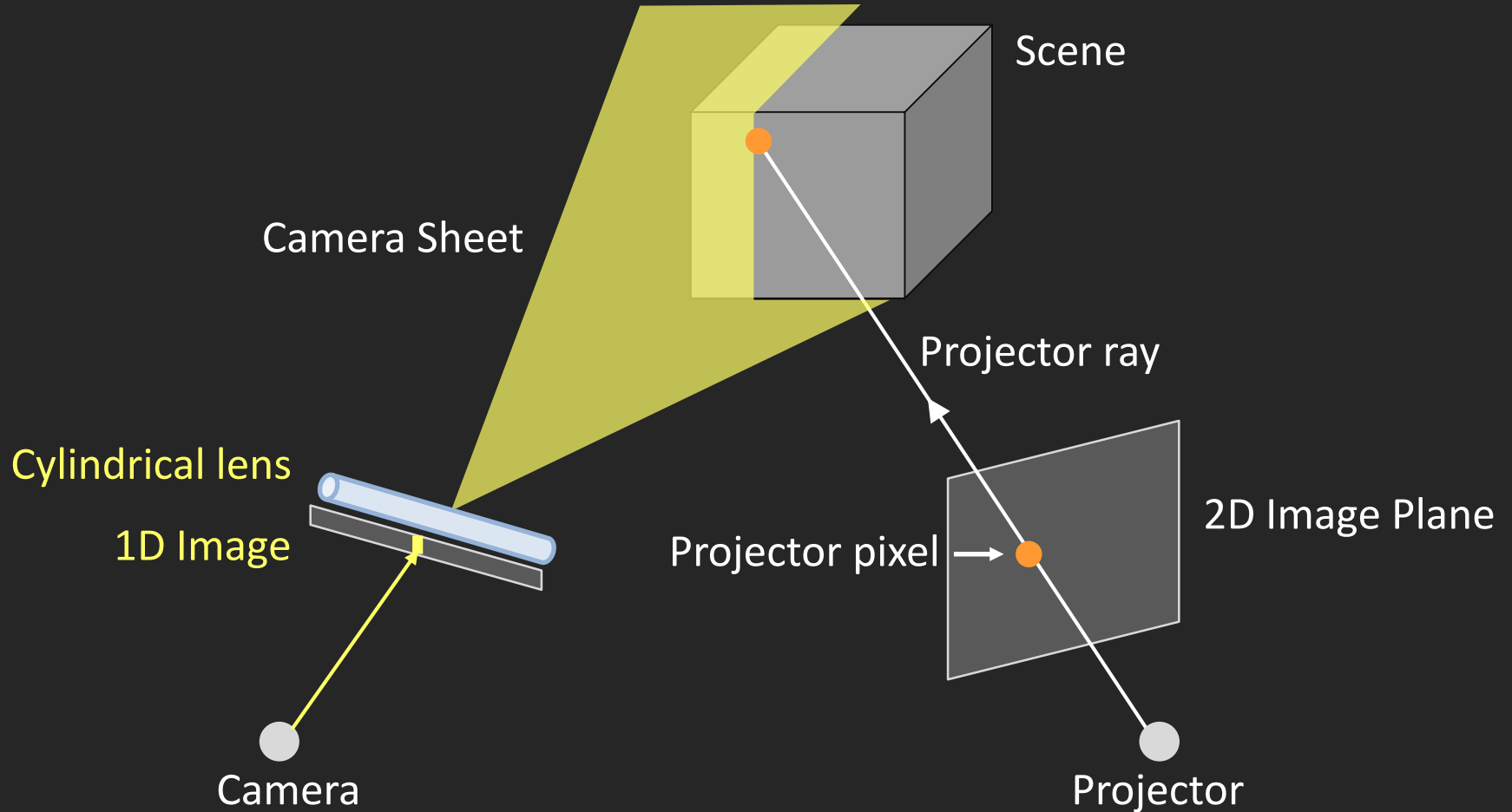
Cylindrical Lens Defocuses Only Along One Direction

Imaging with Cylindrical Lens



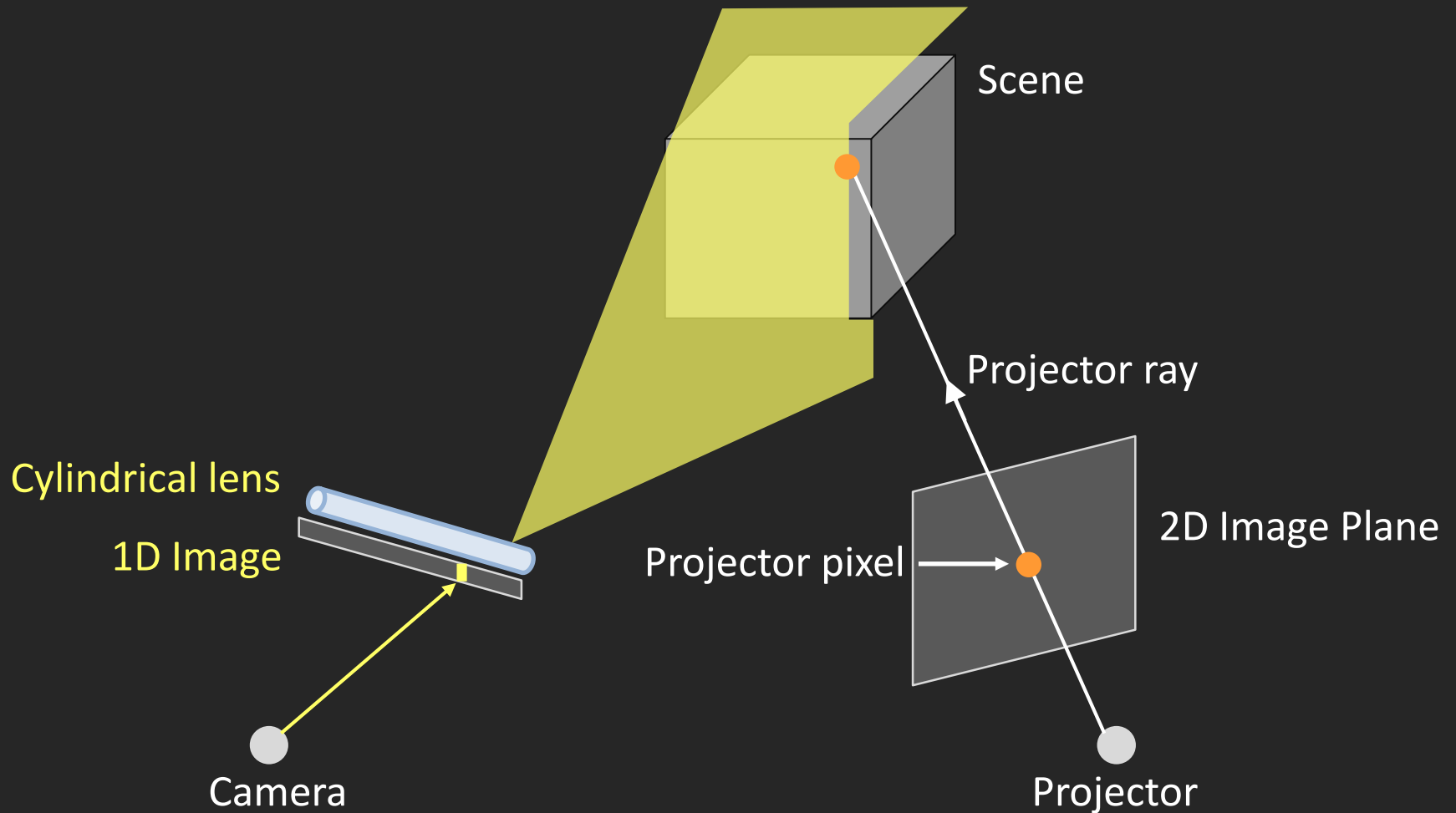
Cylindrical Lens Defocuses Only Along One Direction

Dual Structured Light 3D With 1D Sensor



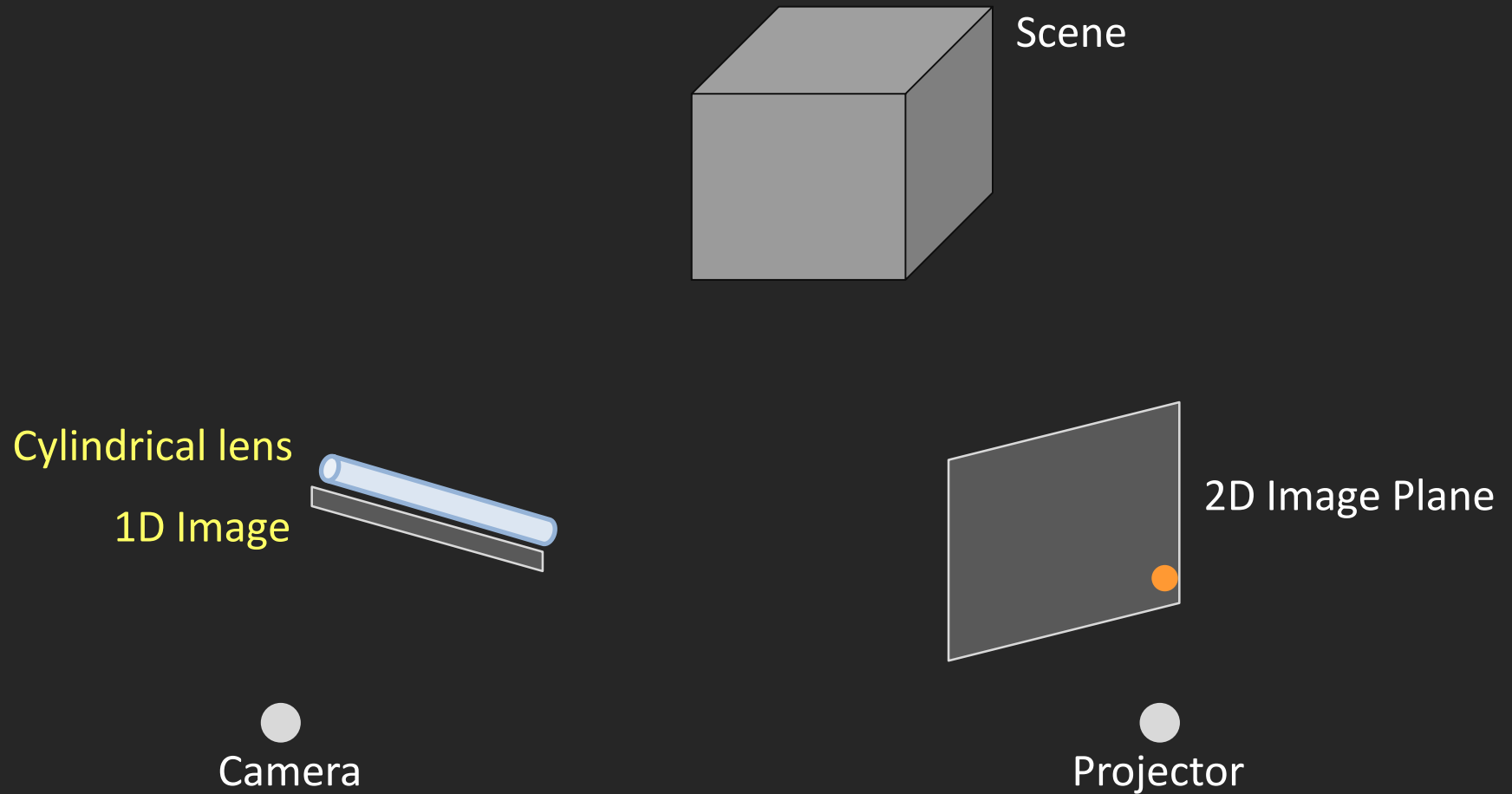
Triangulation of Projector Ray with Camera Plane

Dual Structured Light 3D With 1D Sensor

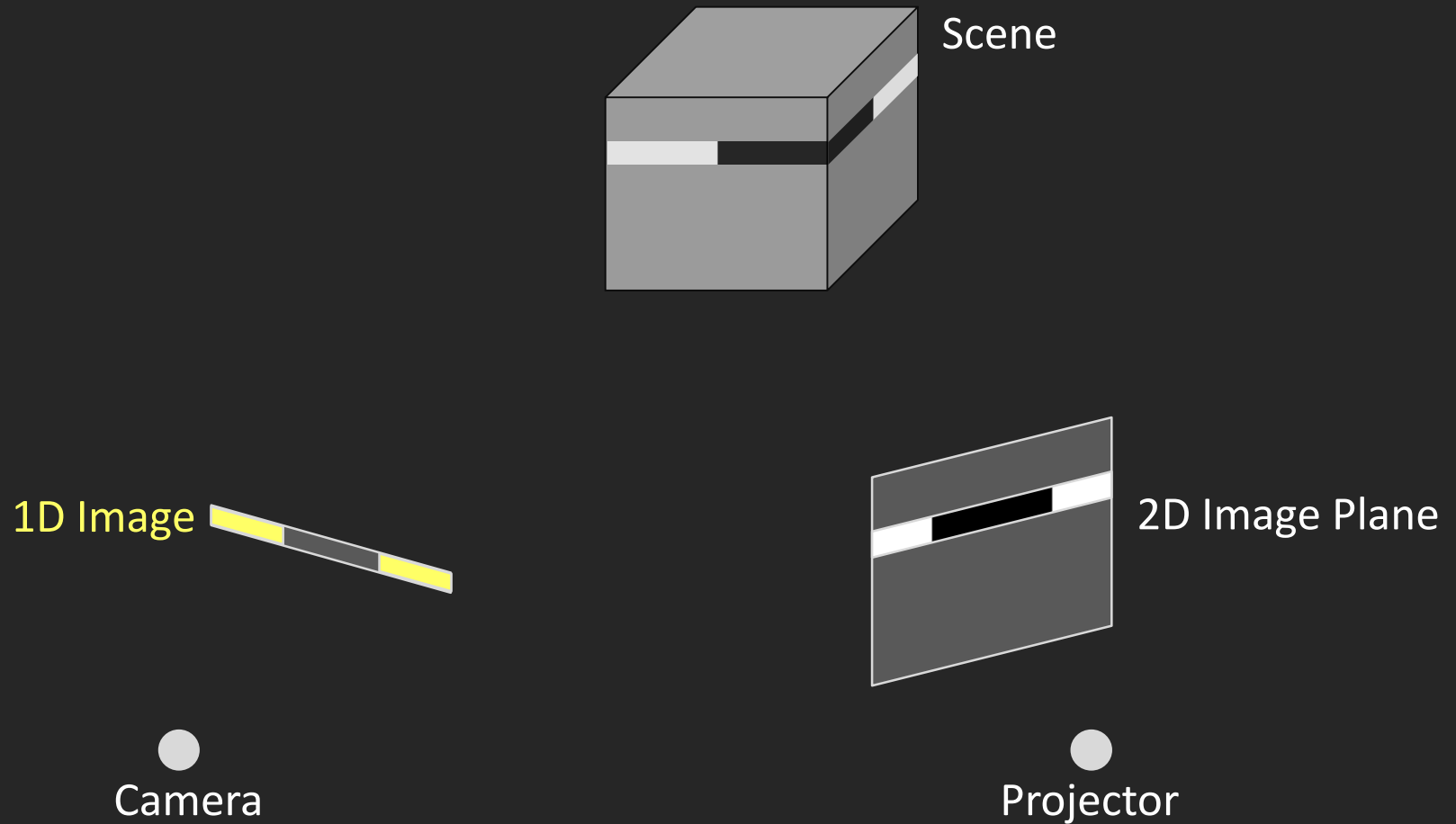


Triangulation of Projector Ray with Camera Plane

Dual Structured Light 3D: Point Scanning

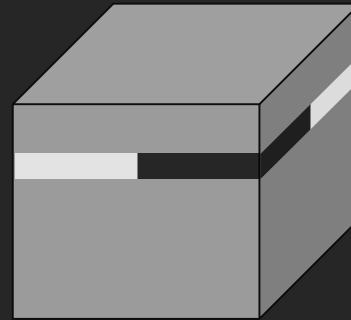
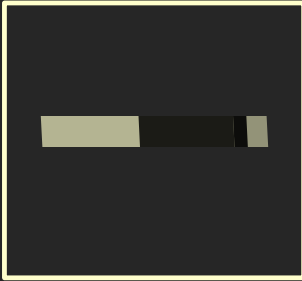


Fast Dual Structured Light 3D

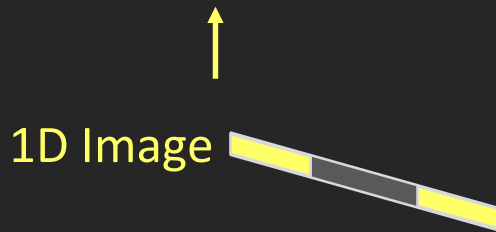


Fast Dual Structured Light 3D

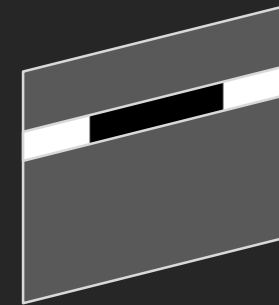
Captured Data



Scene



●
Camera

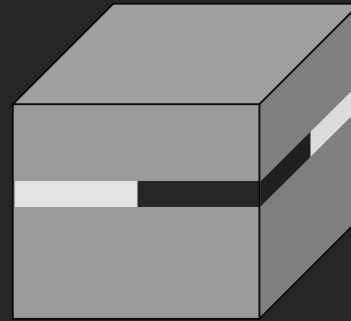
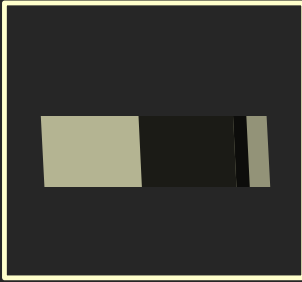


2D Image Plane

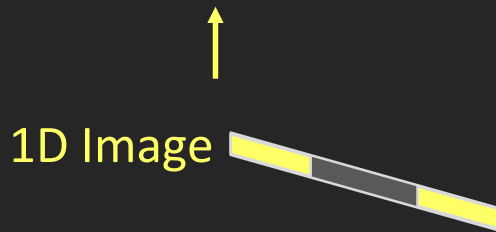
●
Projector

Fast Dual Structured Light 3D

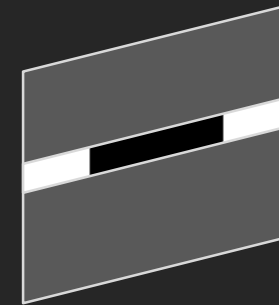
Captured Data



Scene



●
Camera

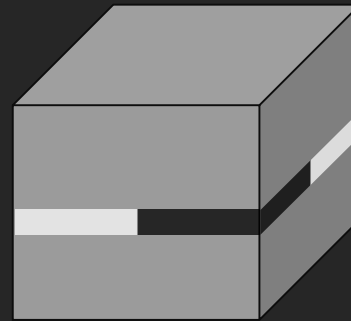
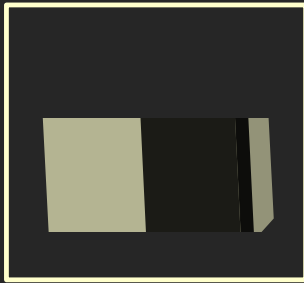


2D Image Plane

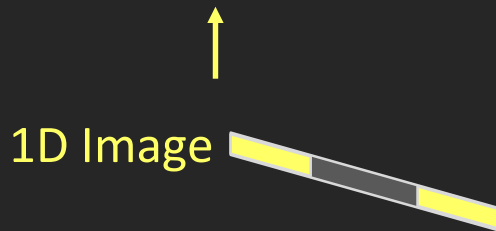
●
Projector

Fast Dual Structured Light 3D

Captured Data



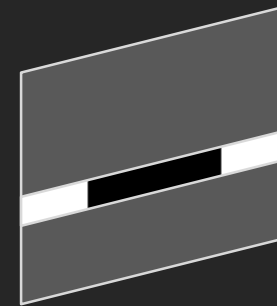
Scene



1D Image



Camera



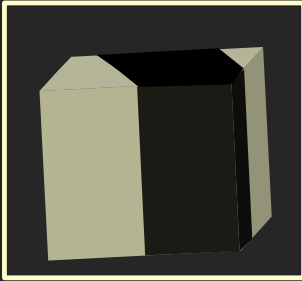
2D Image Plane



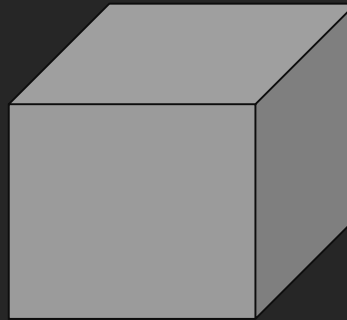
Projector

Fast Dual Structured Light 3D

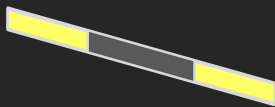
Captured Data



Scene



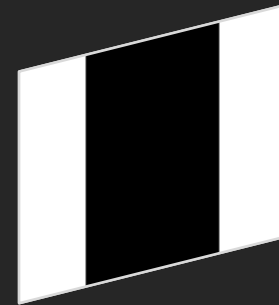
1D Image



Camera



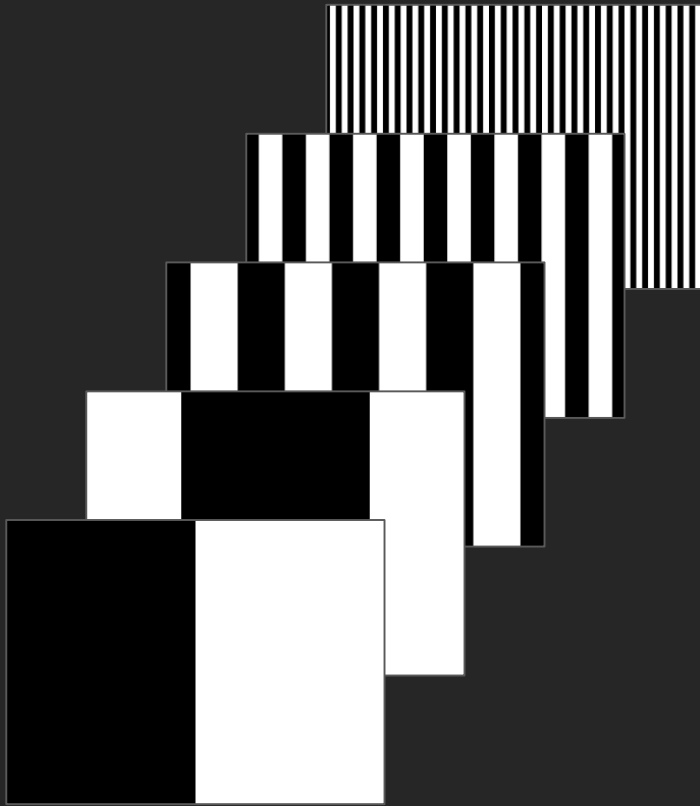
2D Image Plane



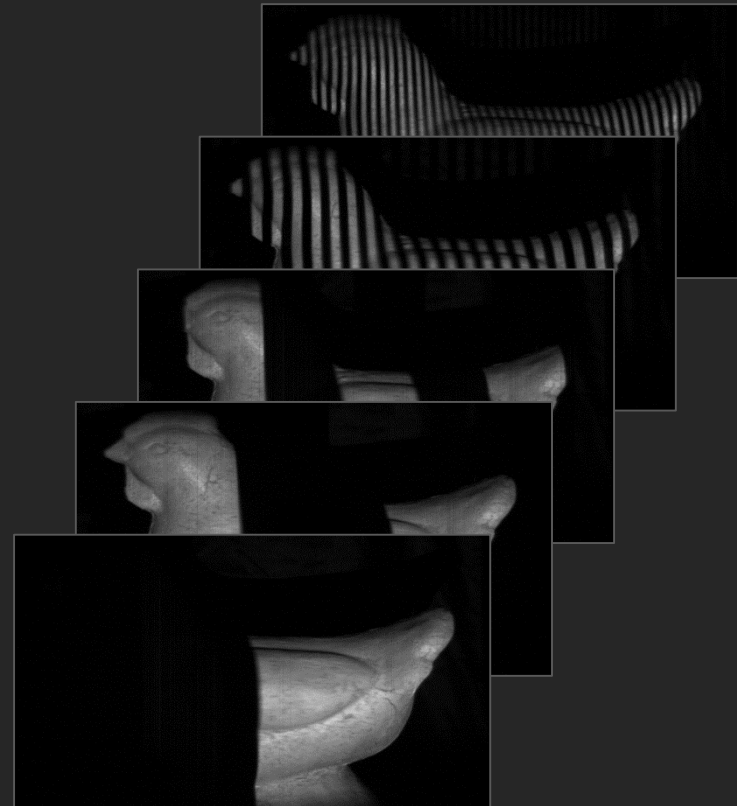
Projector



Example Captured data

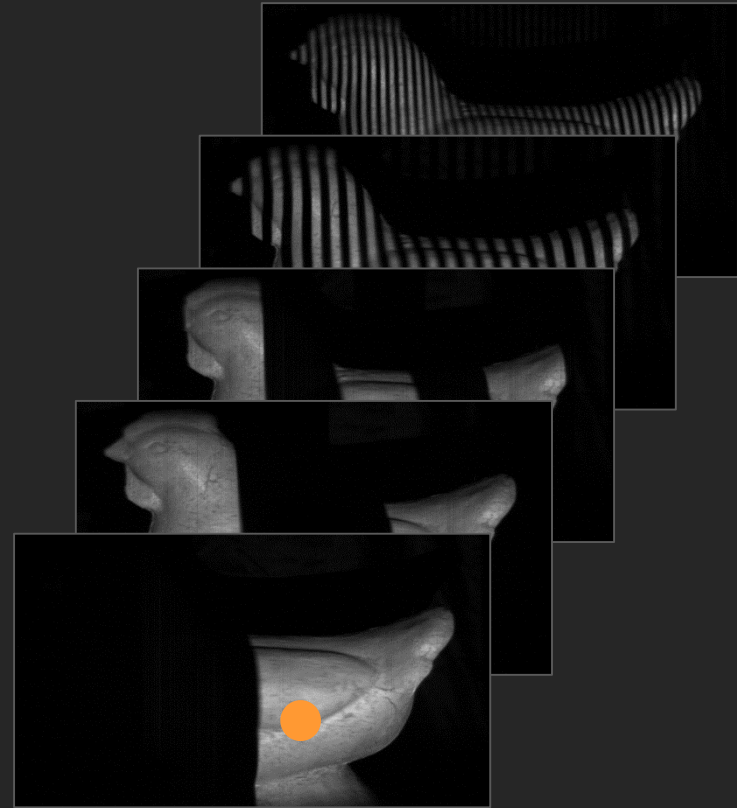


Projector Patterns

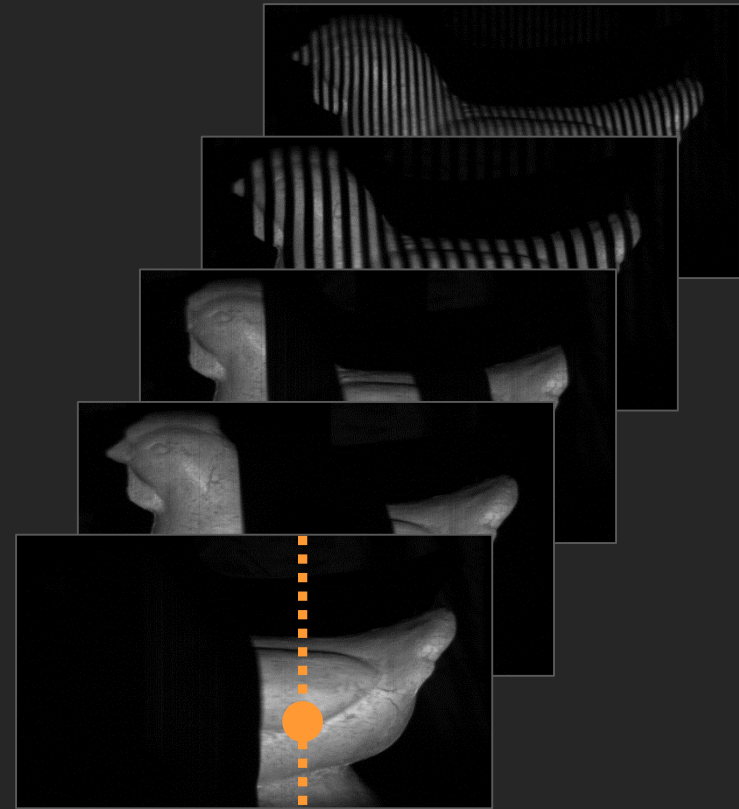


Captured Data

Example Captured data

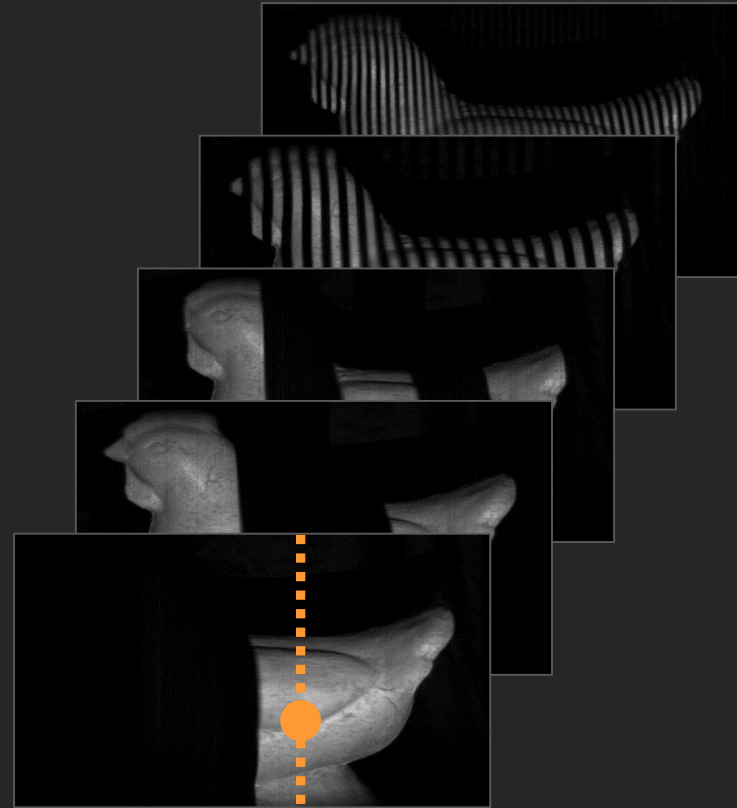


Example Captured data



Sensor Pixel Index

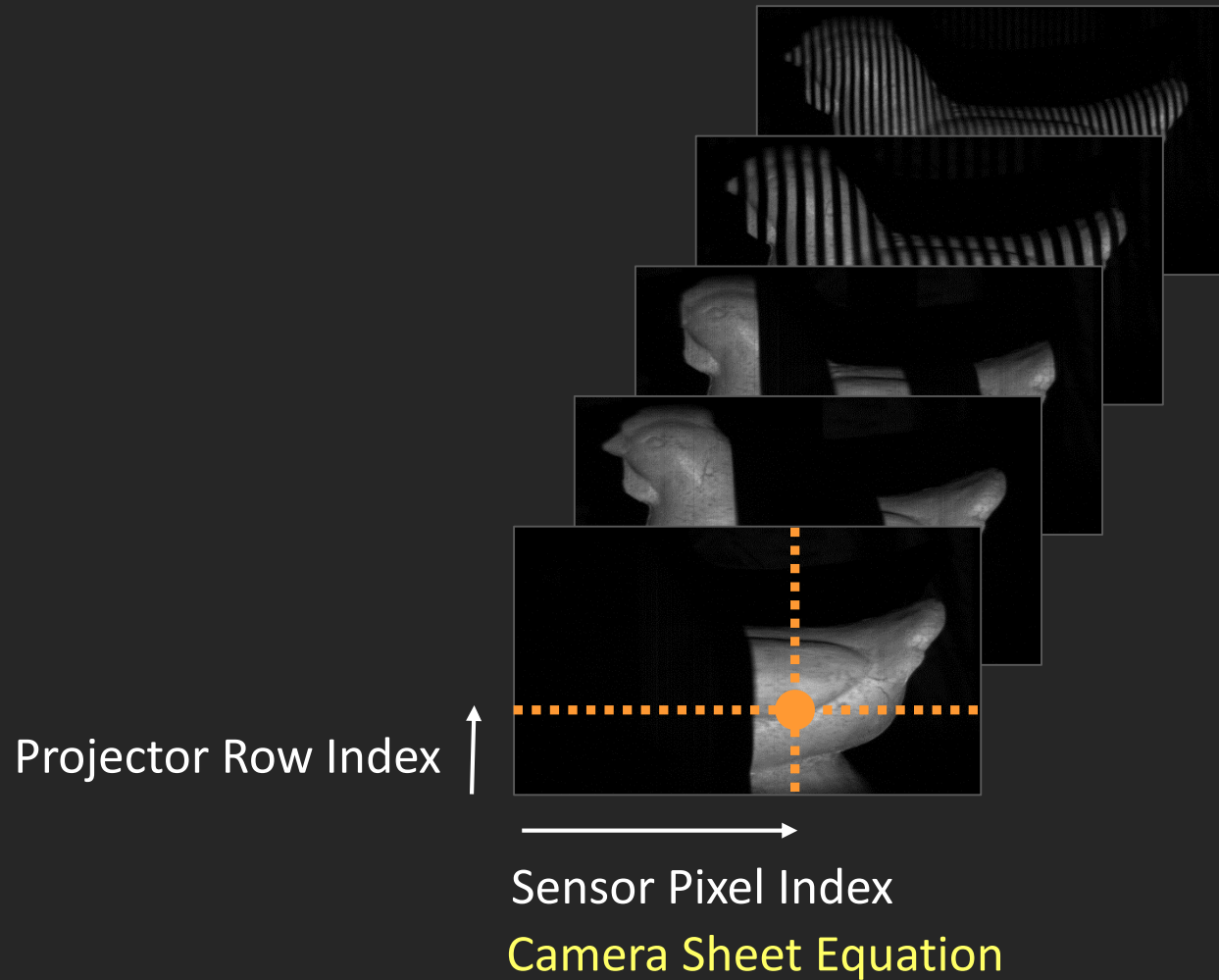
Example Captured data



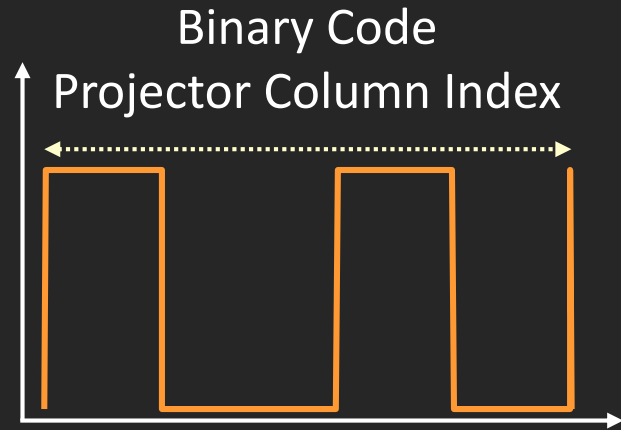
Sensor Pixel Index

Camera Sheet Equation

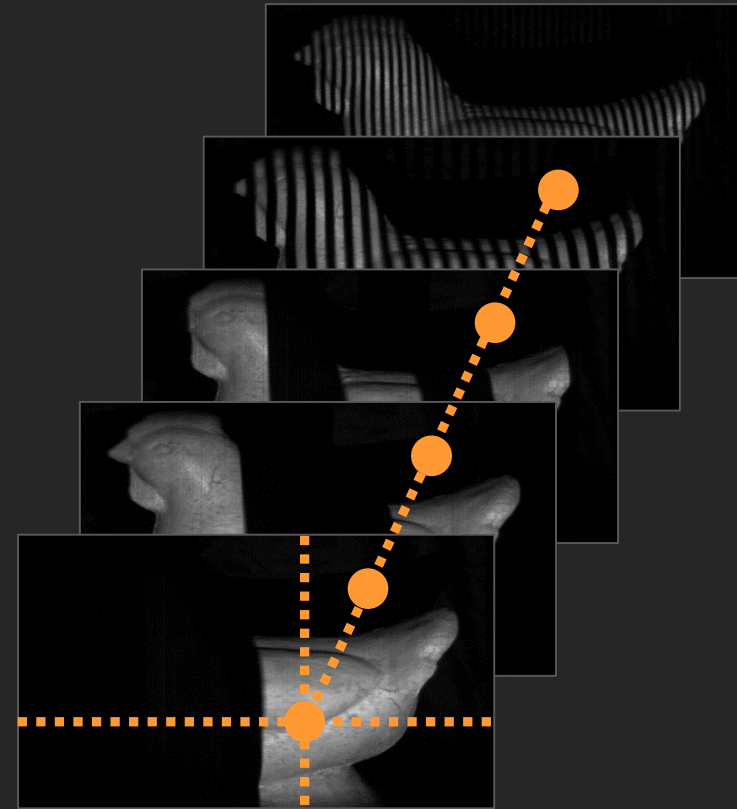
Example Captured data



Example Captured data



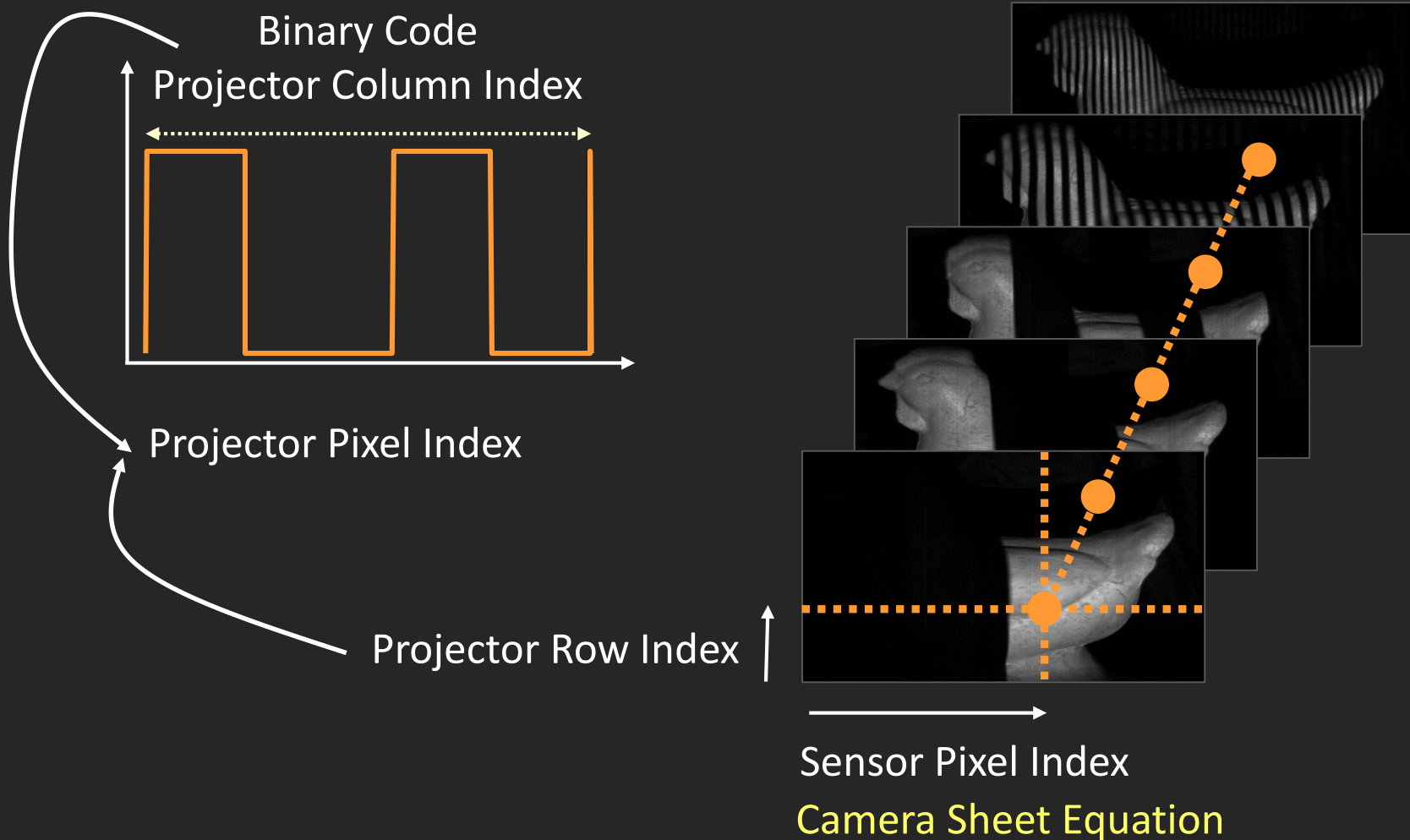
Projector Row Index



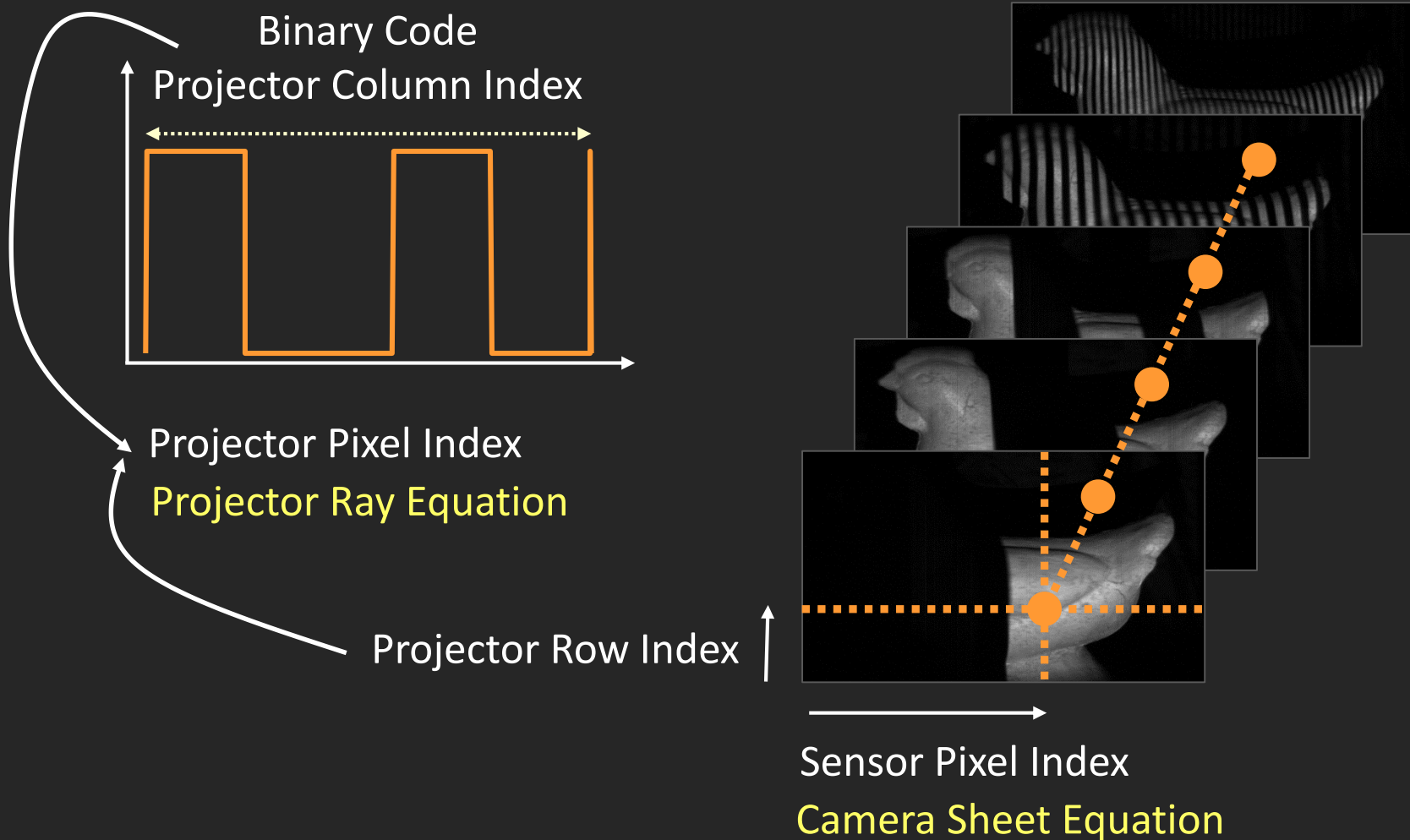
Sensor Pixel Index

Camera Sheet Equation

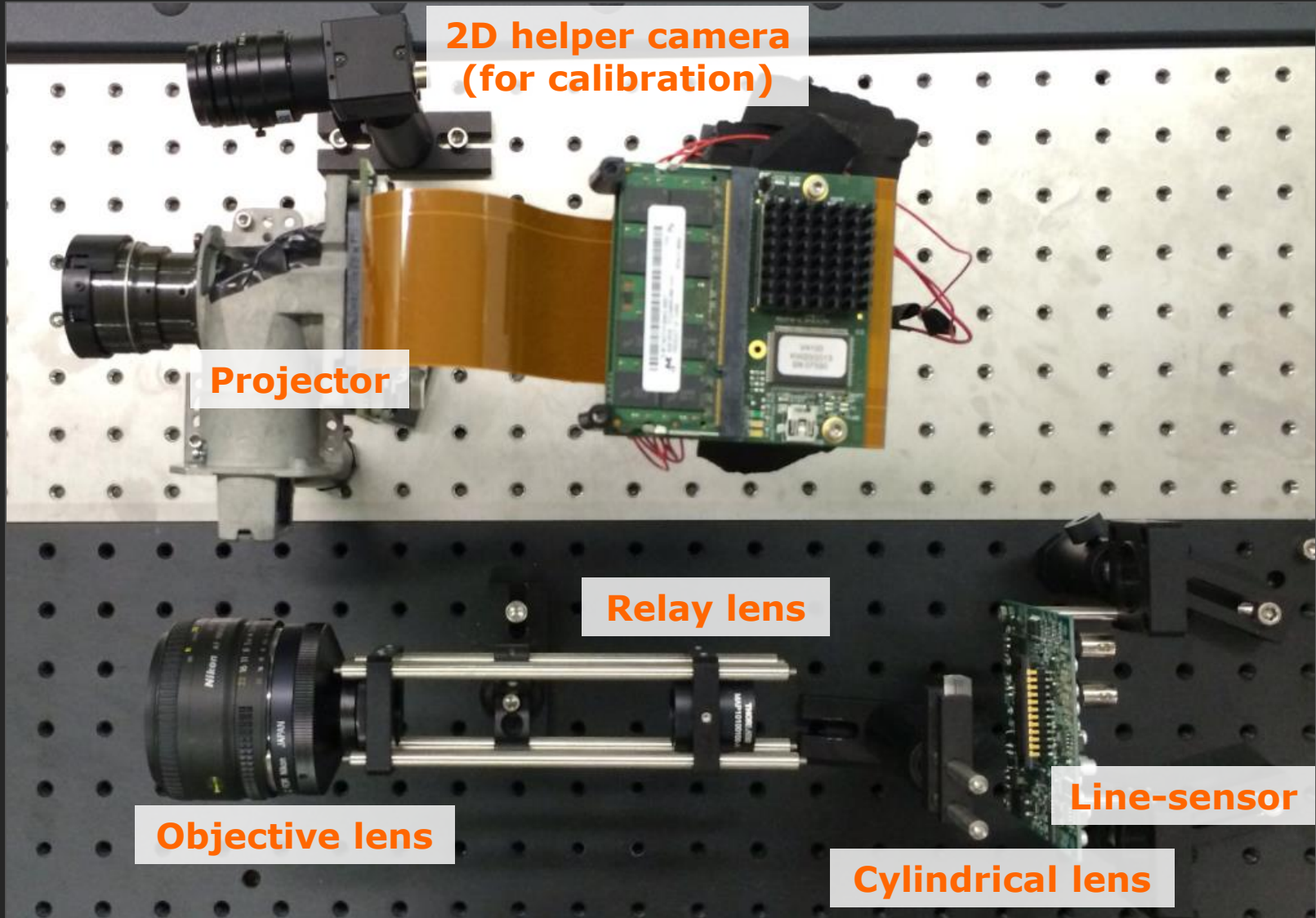
Example Captured data



Example Captured data



Hardware Prototype



Results: 1D Visible Sensor



Scene



3D Reconstruction

Results: 1D Visible Sensor



Scene

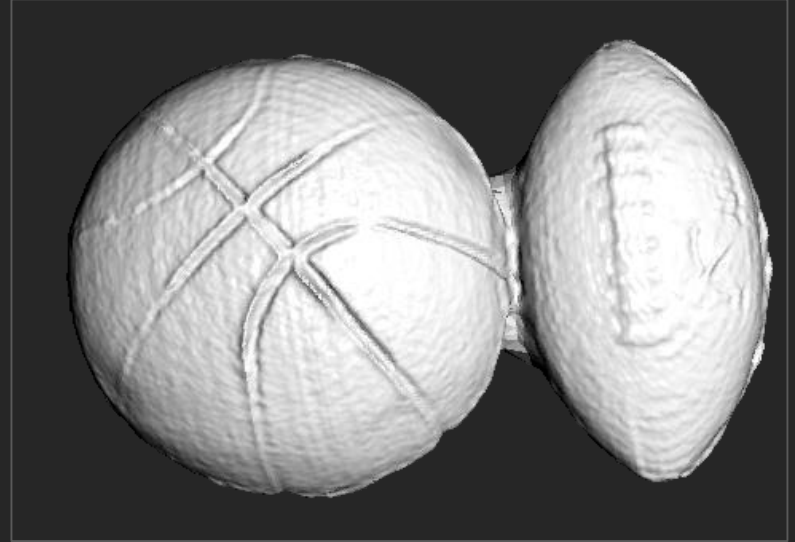


3D Reconstruction

Results: 1D Visible Sensor



Scene

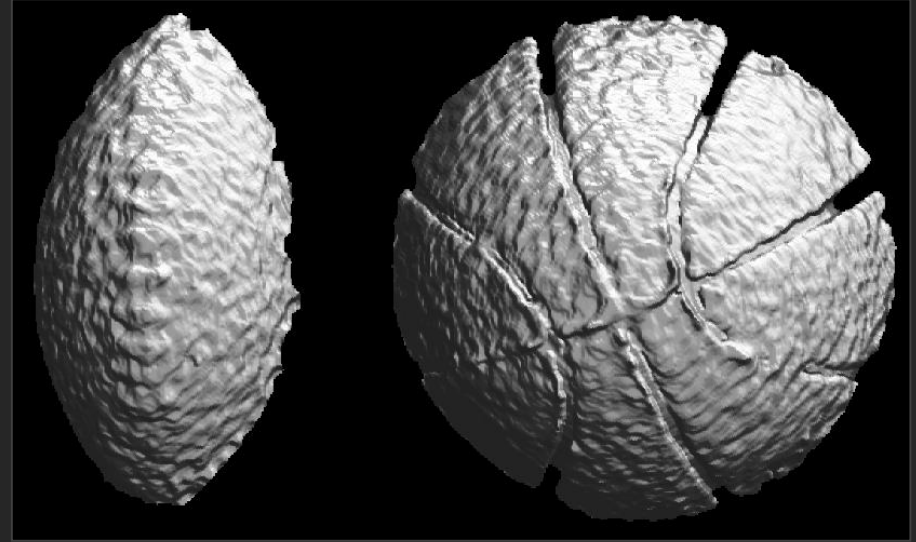


3D Reconstruction

Results: 1D SWIR Sensor

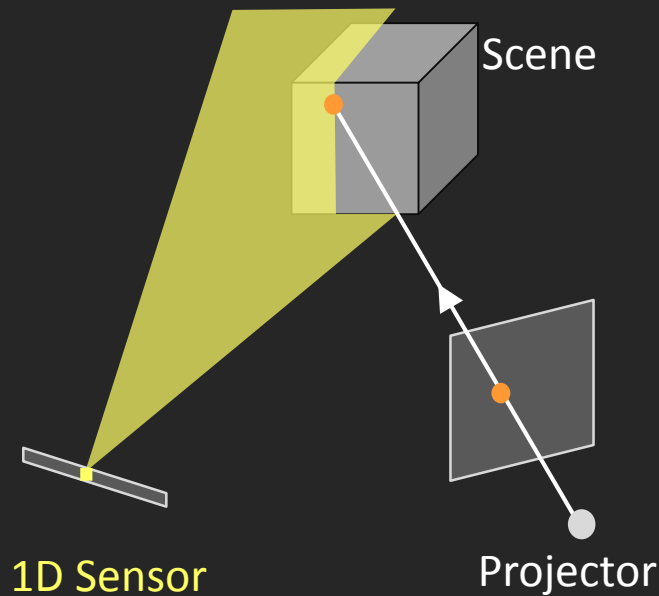


Scene



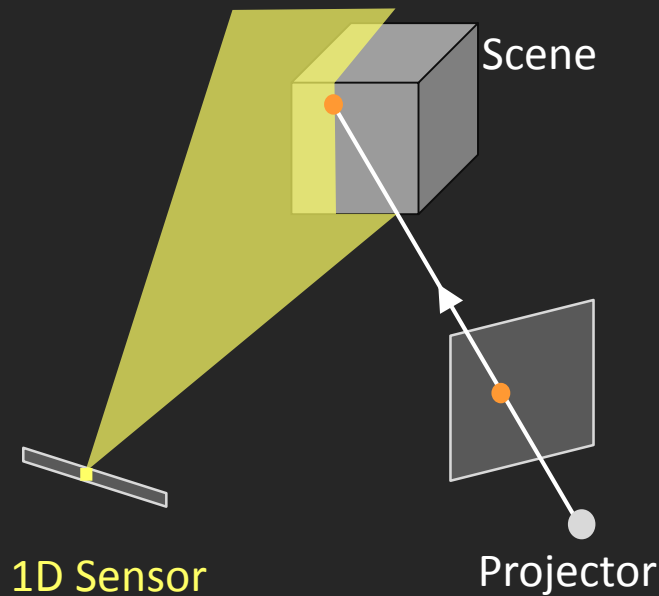
3D Reconstruction

Summary: Dual Structured Light



Dual Structured Light 3D
Using 1D Sensor

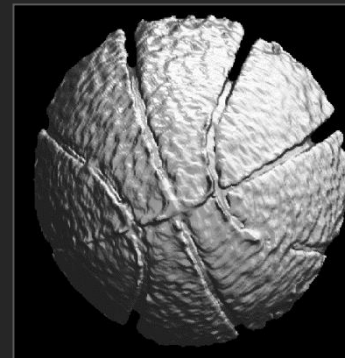
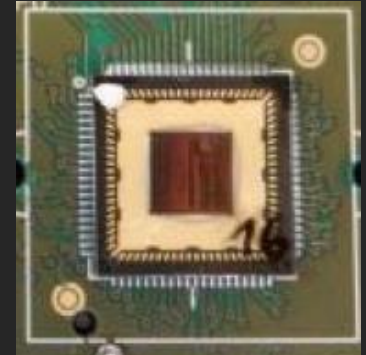
Summary: Dual Structured Light



1D Short-Wave
IR Sensor



1D Dynamic Vision
Sensor



Dual Structured Light 3D
Using 1D Sensor

Extreme 3D Imaging Using
SWIR and Other Sensors