Prakash: Lighting-Aware Motion Capture Using Photosensing Markers and Multiplexed Illuminators

R Raskar, H Nii, B de Decker, Y Hashimoto, J Summet, D Moore, Y Zhao, J Westhues, P Dietz, M Inami, S Nayar, J Barnwell, M Noland, P Bekaert, V Branzoi, E Bruns

Mitsubishi Electric Research Labs (MERL)
Cambridge, MA

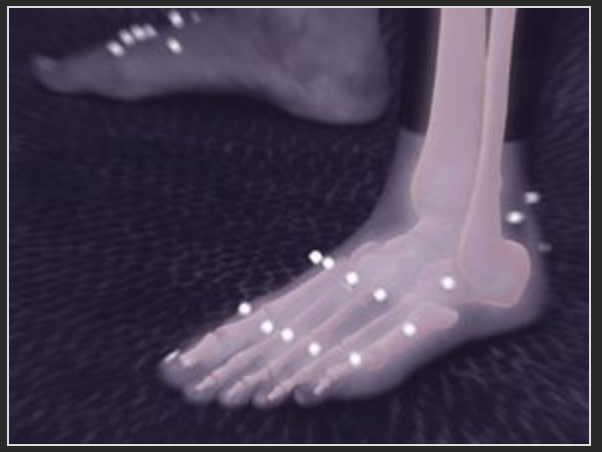
Vicon Motion Capture

High-speed IR Camera

Medical Rehabilitation

Athlete Analysis

Performance Capture

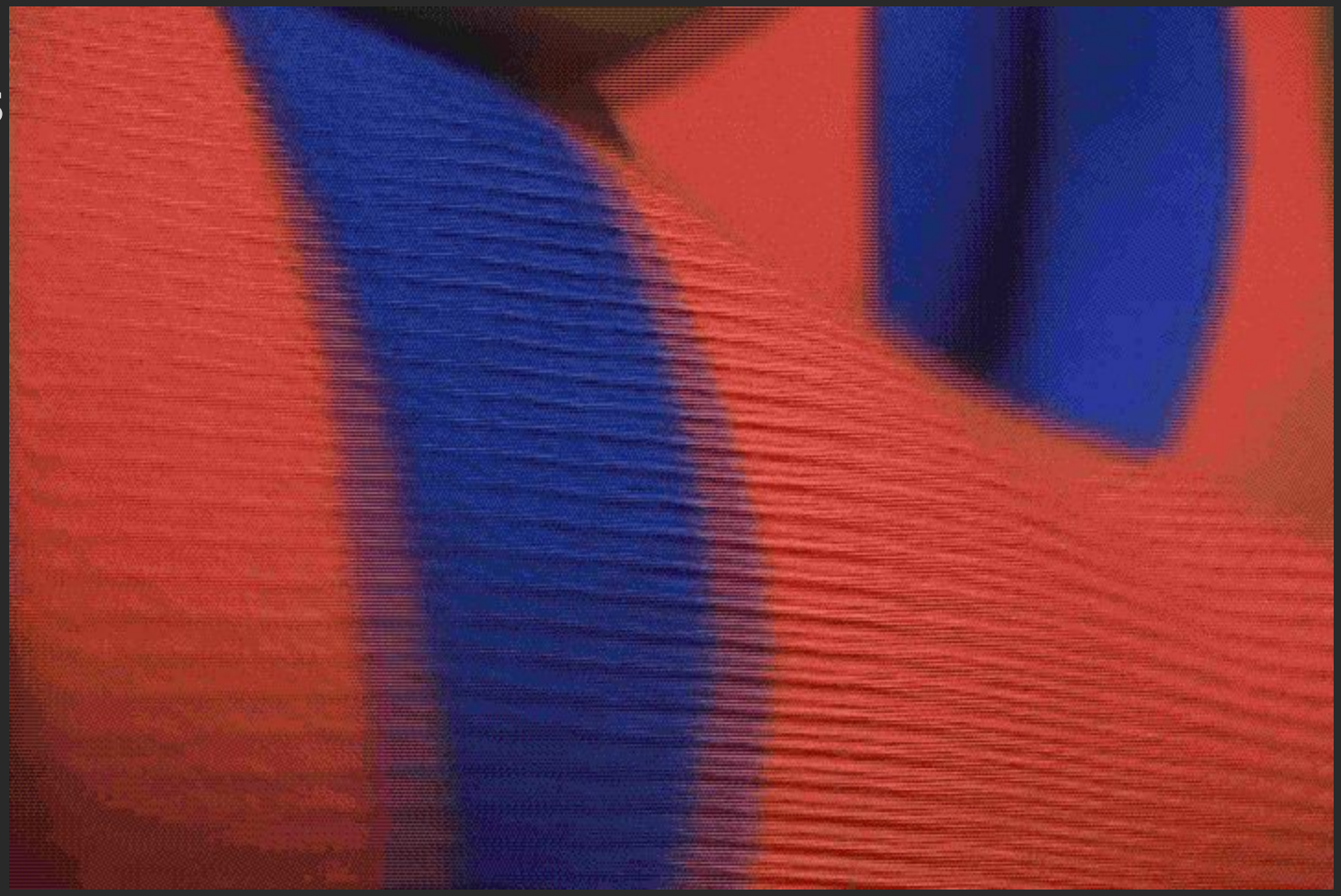


Biomechanical Analysis

Hidden
Marker Tags

Outdoors

Unique Id



Inverse Optical Mo-Cap

High Speed Camera

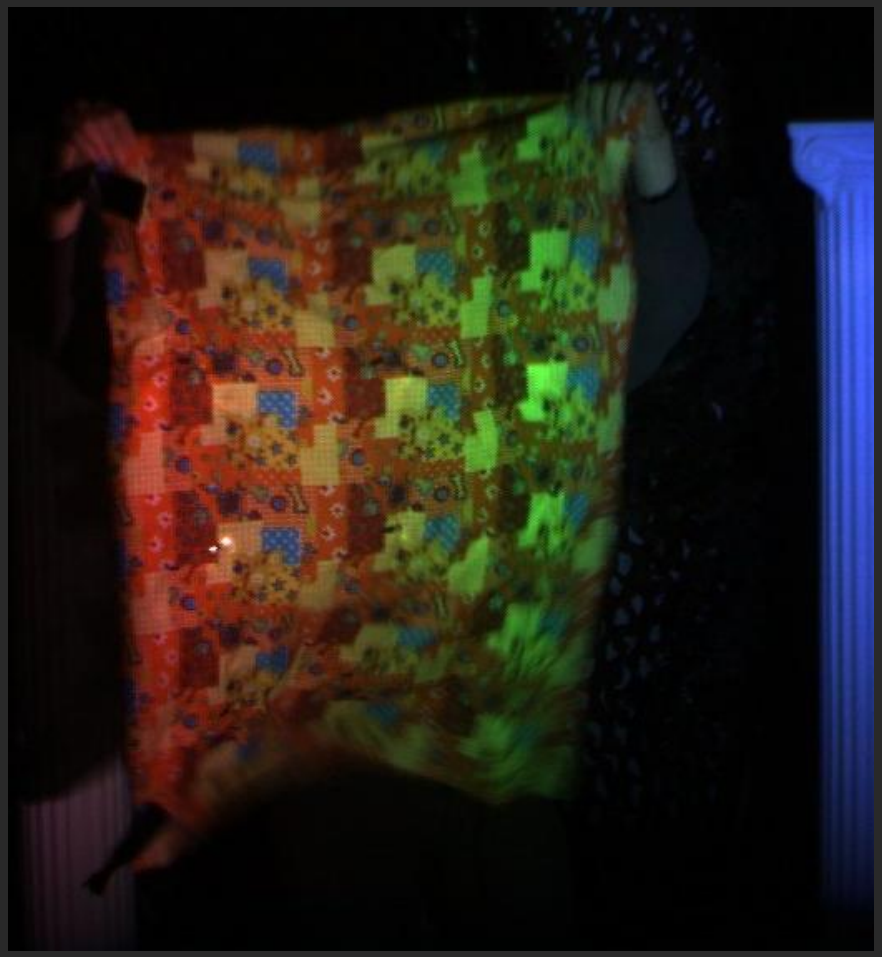
High Speed Projector

Reflecting/Emitting Marker

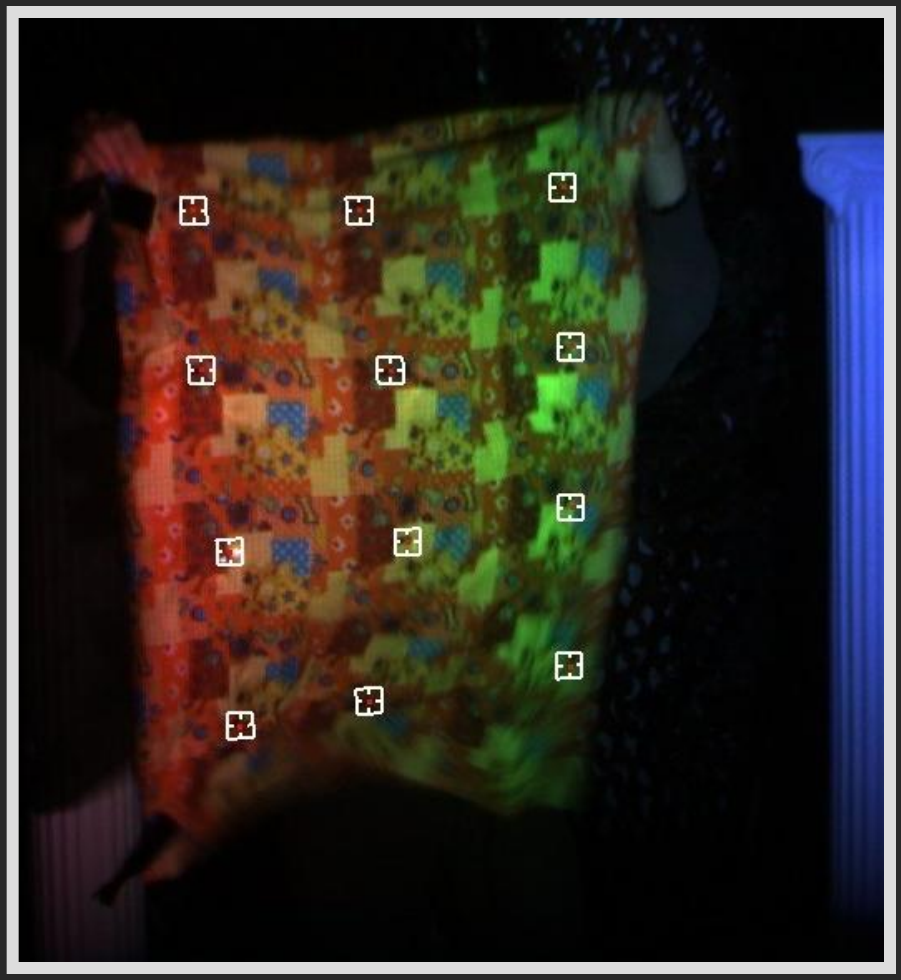
Only Location

Photosensing Marker

Location, Orientation, Illum

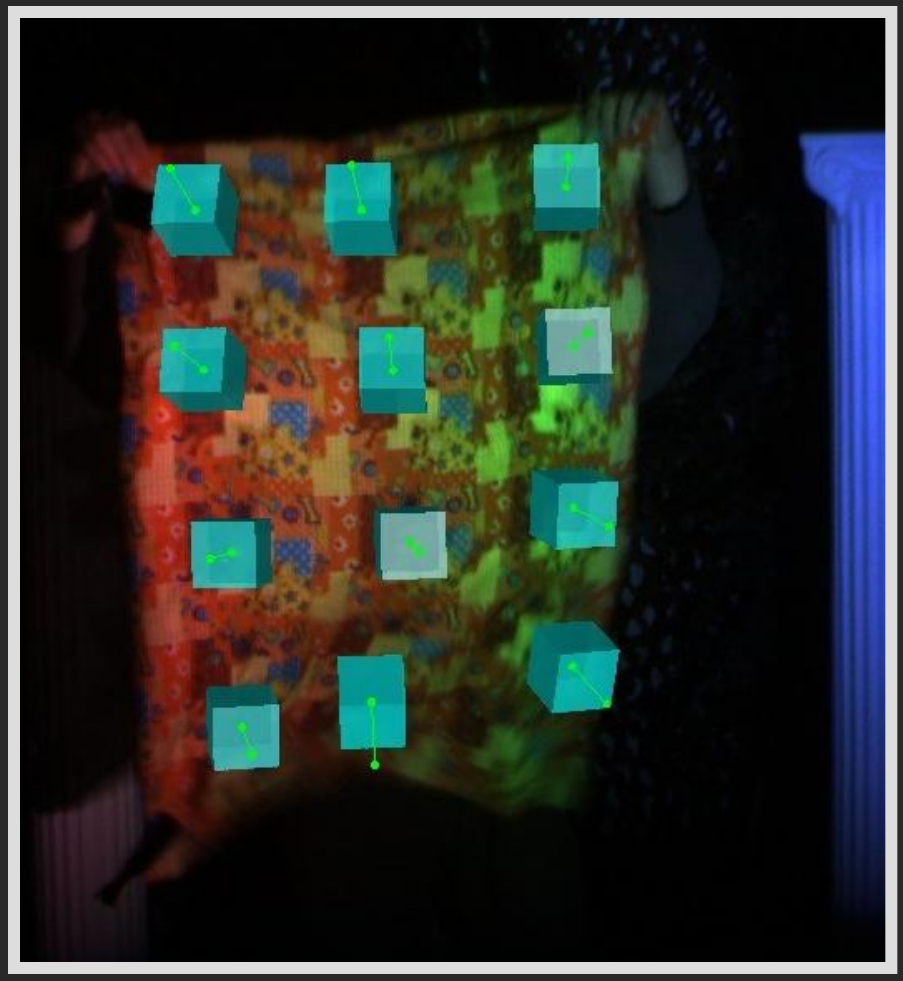


Imperceptible Tags

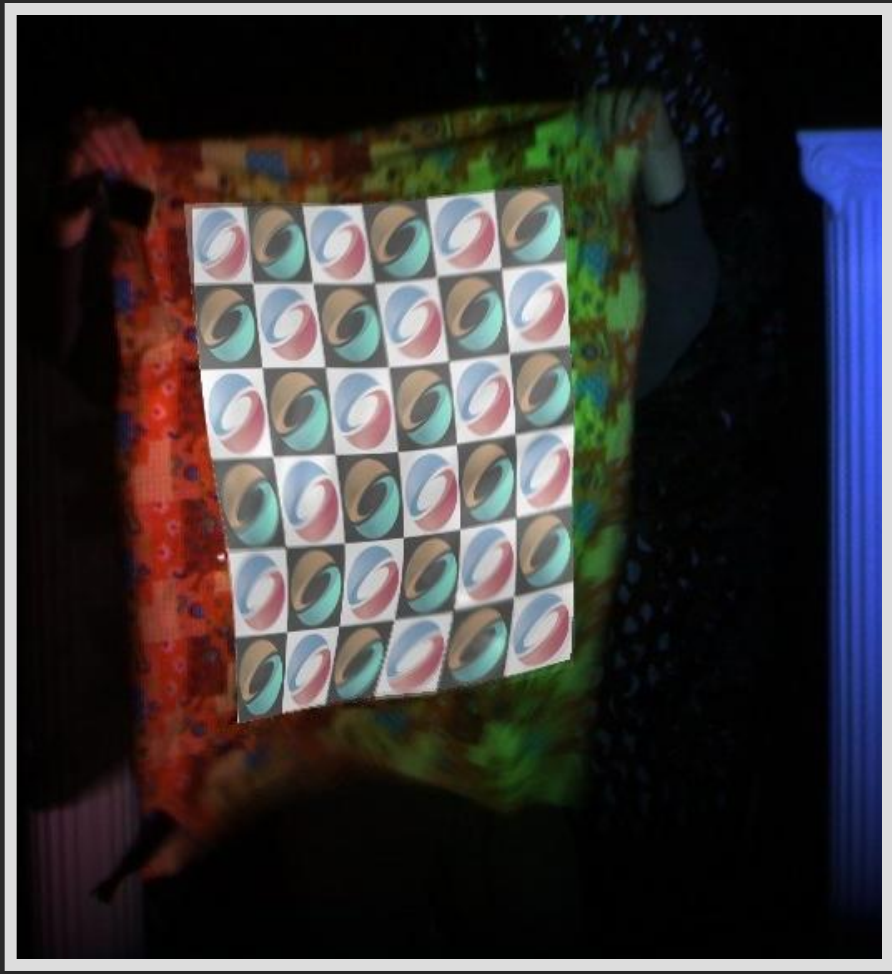


Location

Location

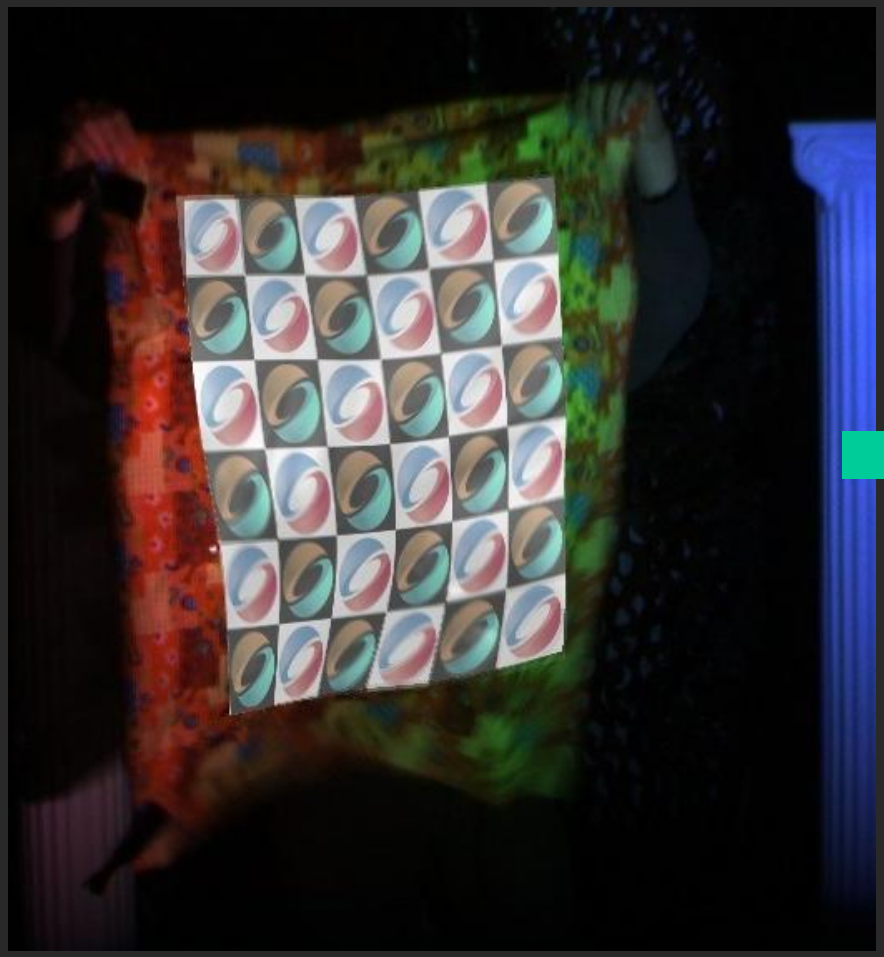


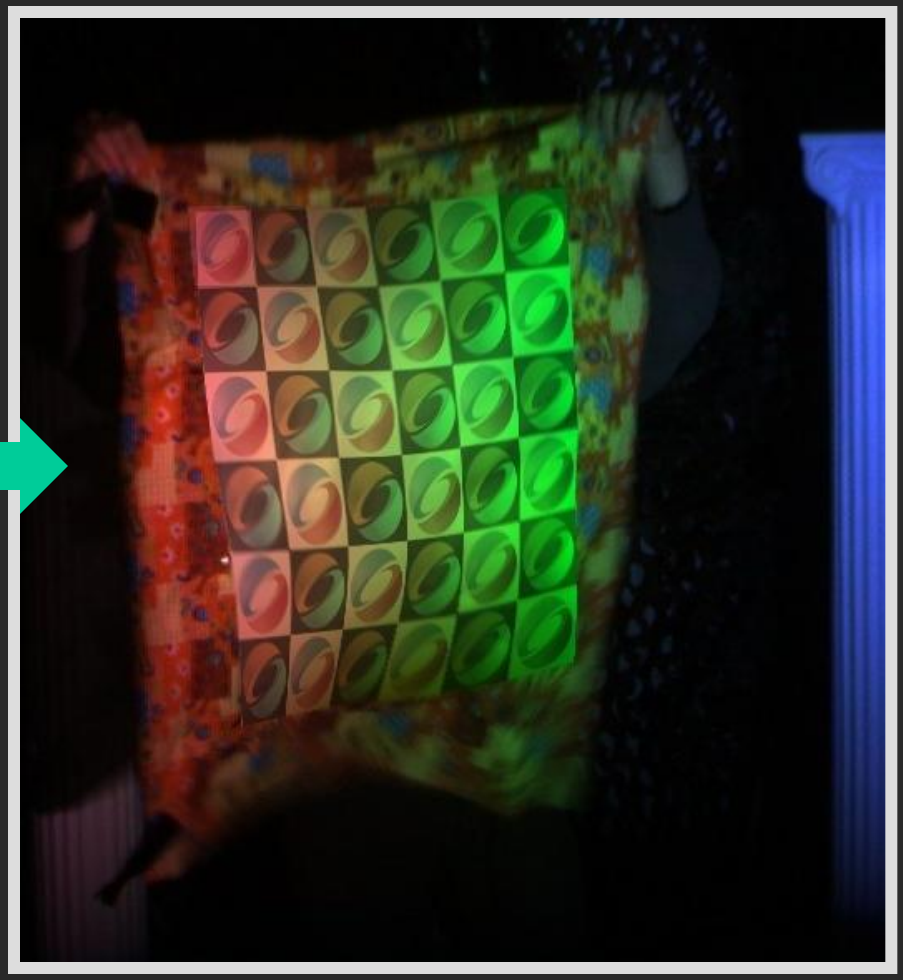
Orientation



3D Overlay

Orientation



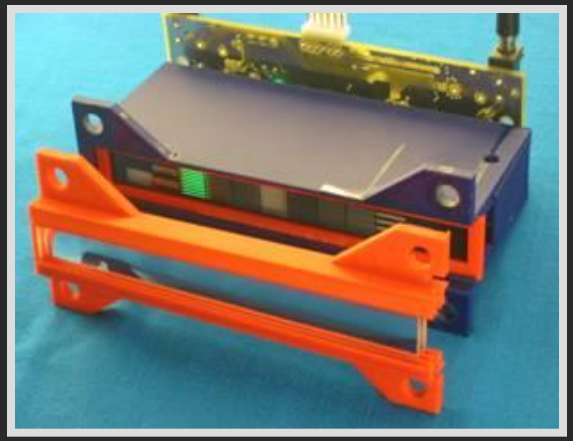


Imperceptible Tags

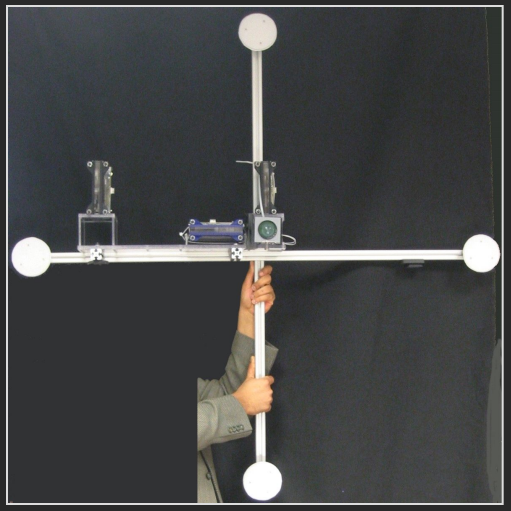
Incident Illumination

Prakash: Lighting-aware Mo-Cap

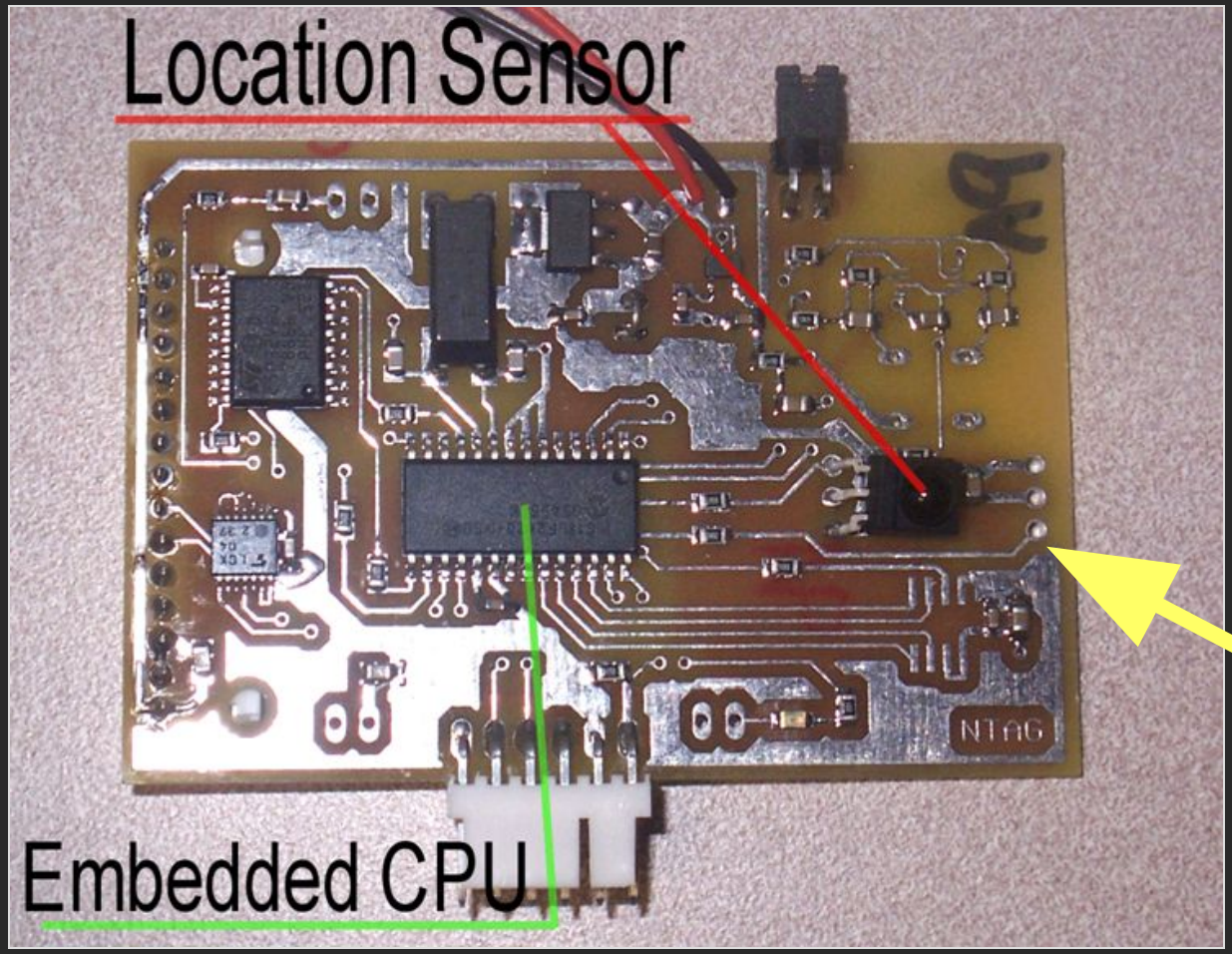
- Geometry via Space Labeling
  - Binary
    - **High speed LED projector**
    - **3D location**

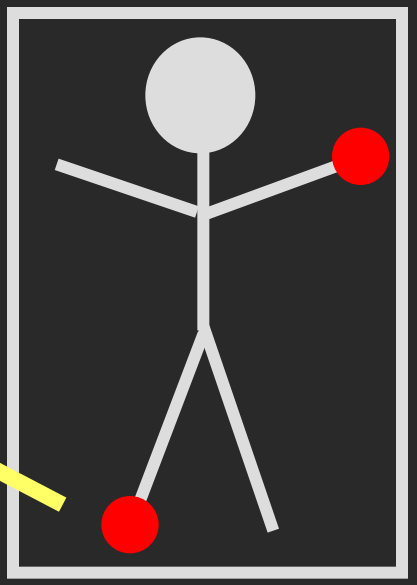


  - Analog
    - Bright Beacons
    - Orientation

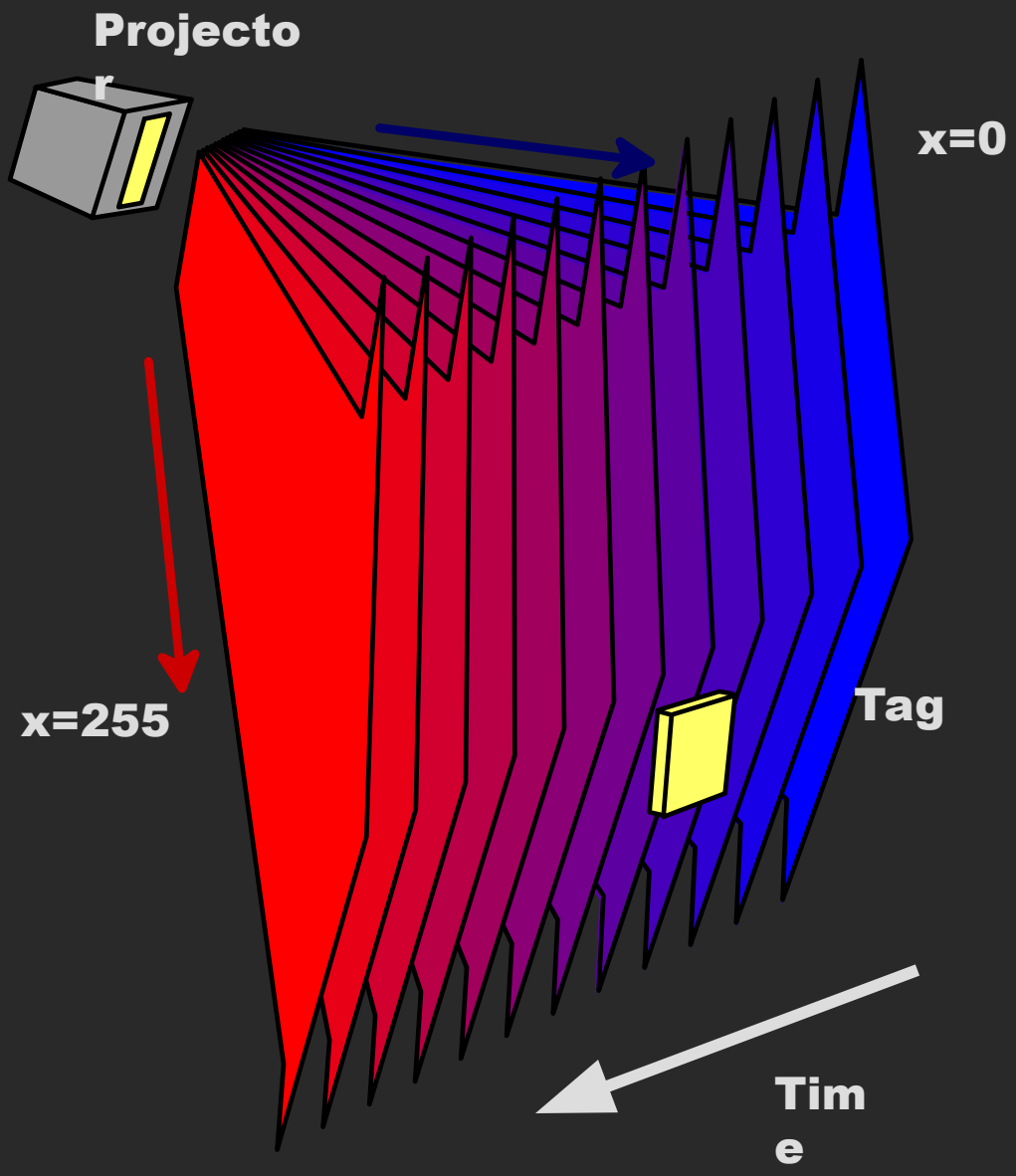


Photosensing Marker Tag





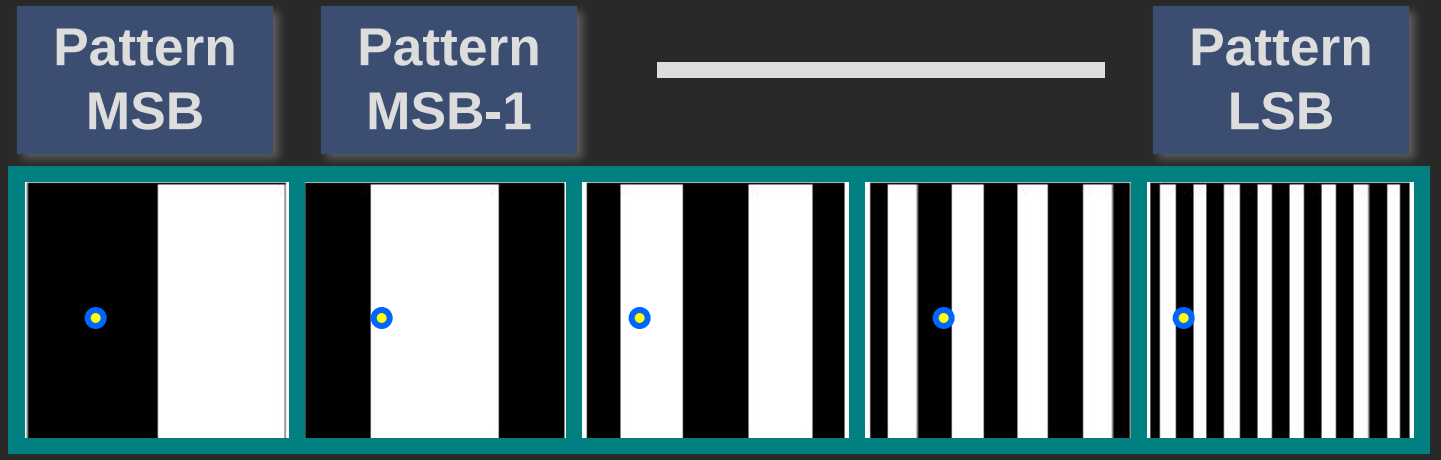
Labeling Space (Indoor GPS)



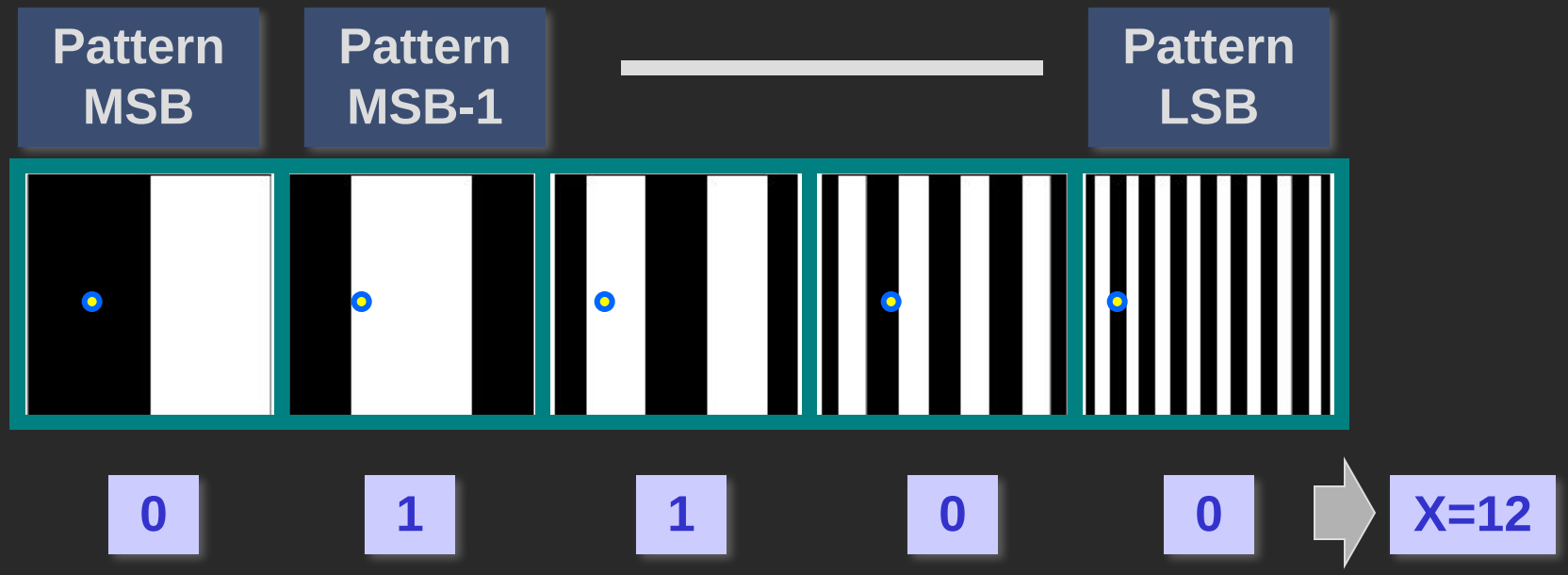
Each location receives a unique temporal code

But 60Hz video projector is too slow

Binary Gray-codes



Binary Gray-codes



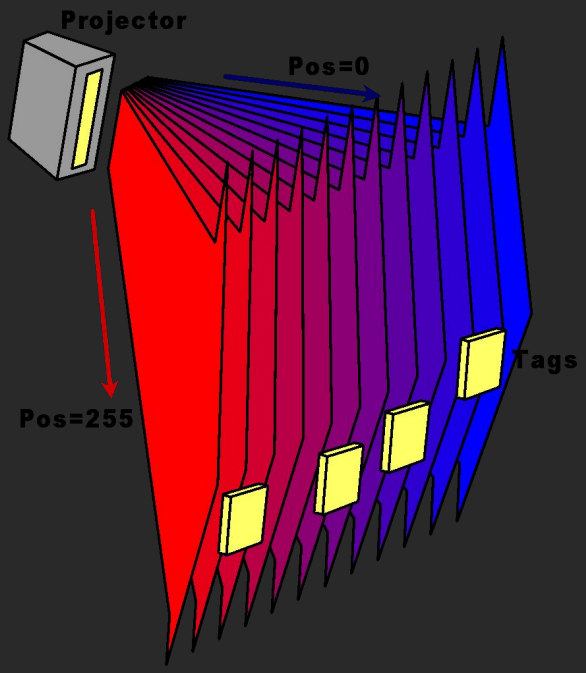
For each tag

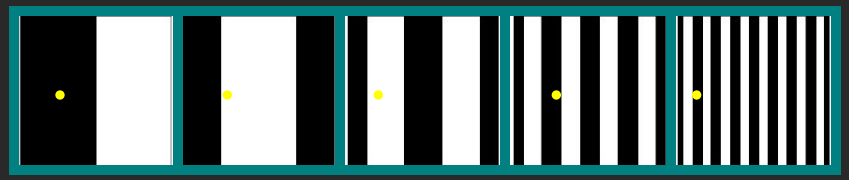
a. From projected pattern sequence, decode *x* coordinate

b. From projected pattern sequence, decode *y* coordinate

c. Transmit back (*Id, x, y*)

Fast Pattern Projector?

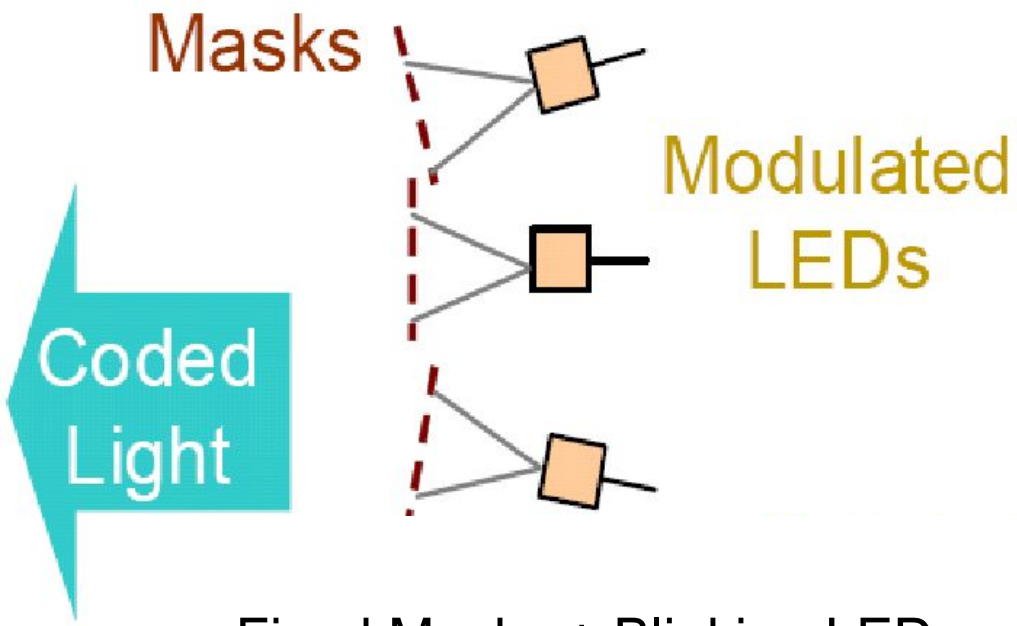




60 Hz => 3 location/sec

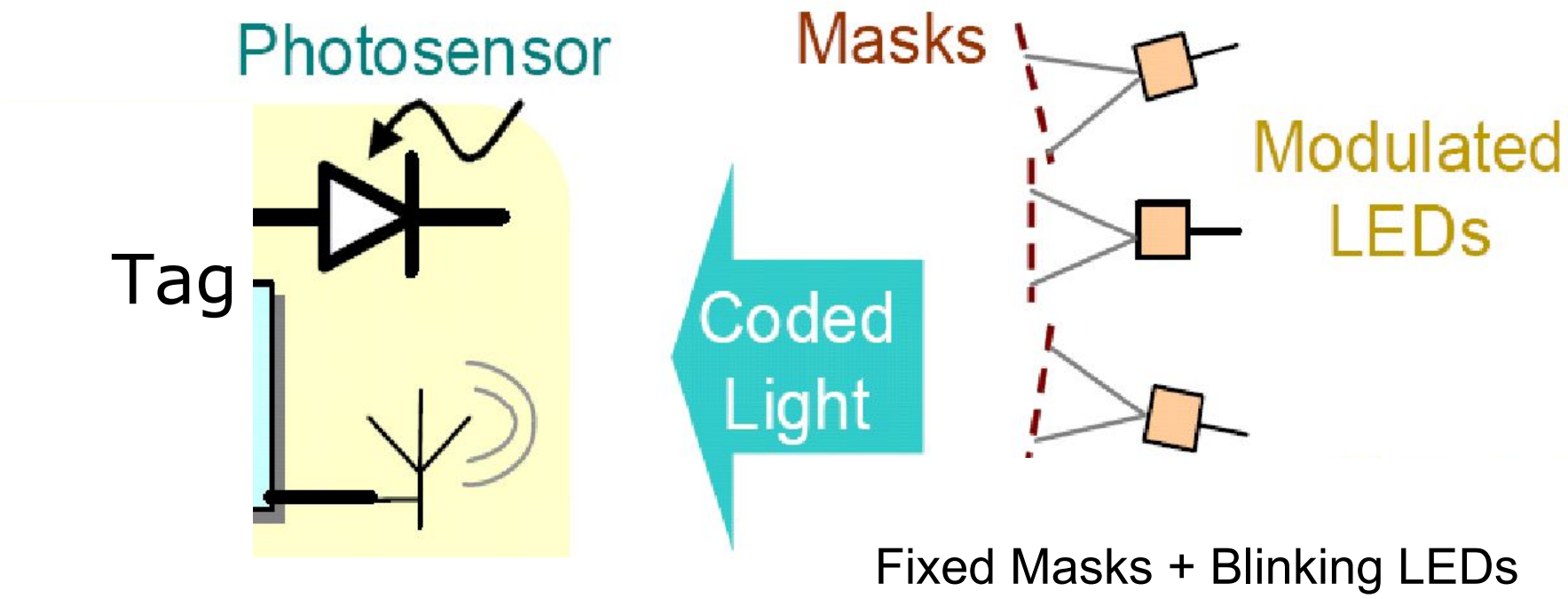
10,000 Hz <= 500 locations/sec !

Fast Switching using Non-colocated Emitters for Structured Light

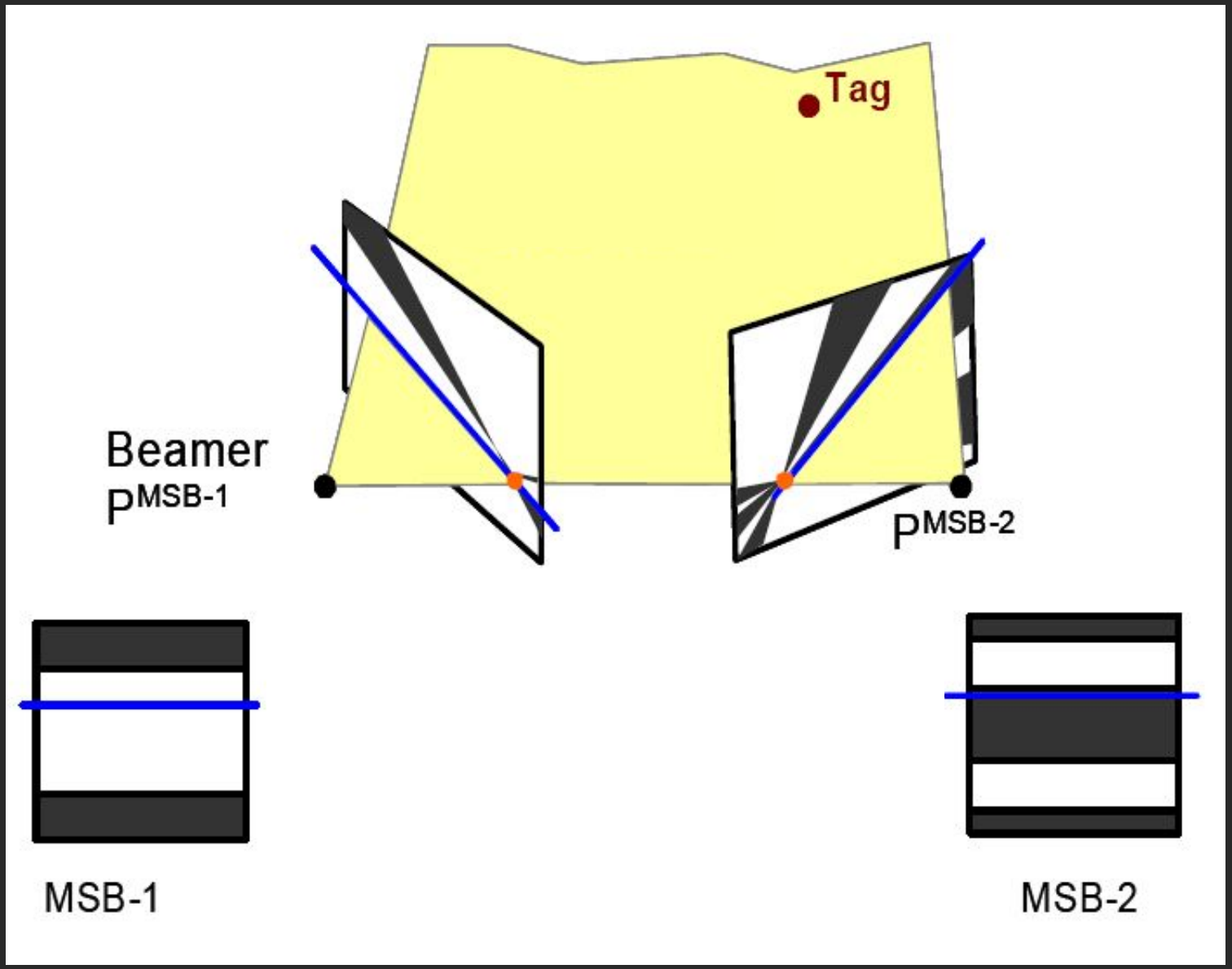


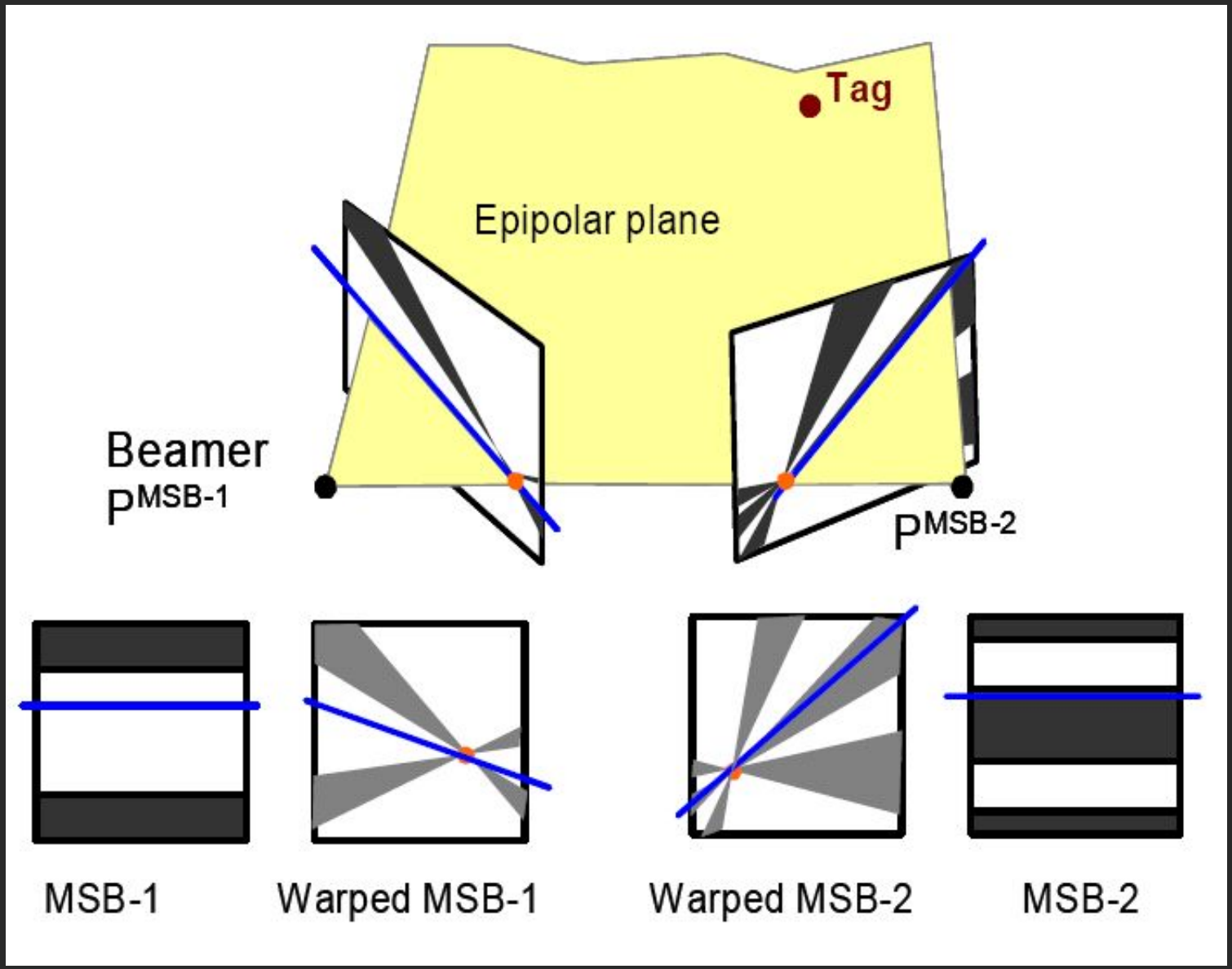
Fixed Masks + Blinking LEDs

Fast Switching using Non-colocated Emitters for Structured Light

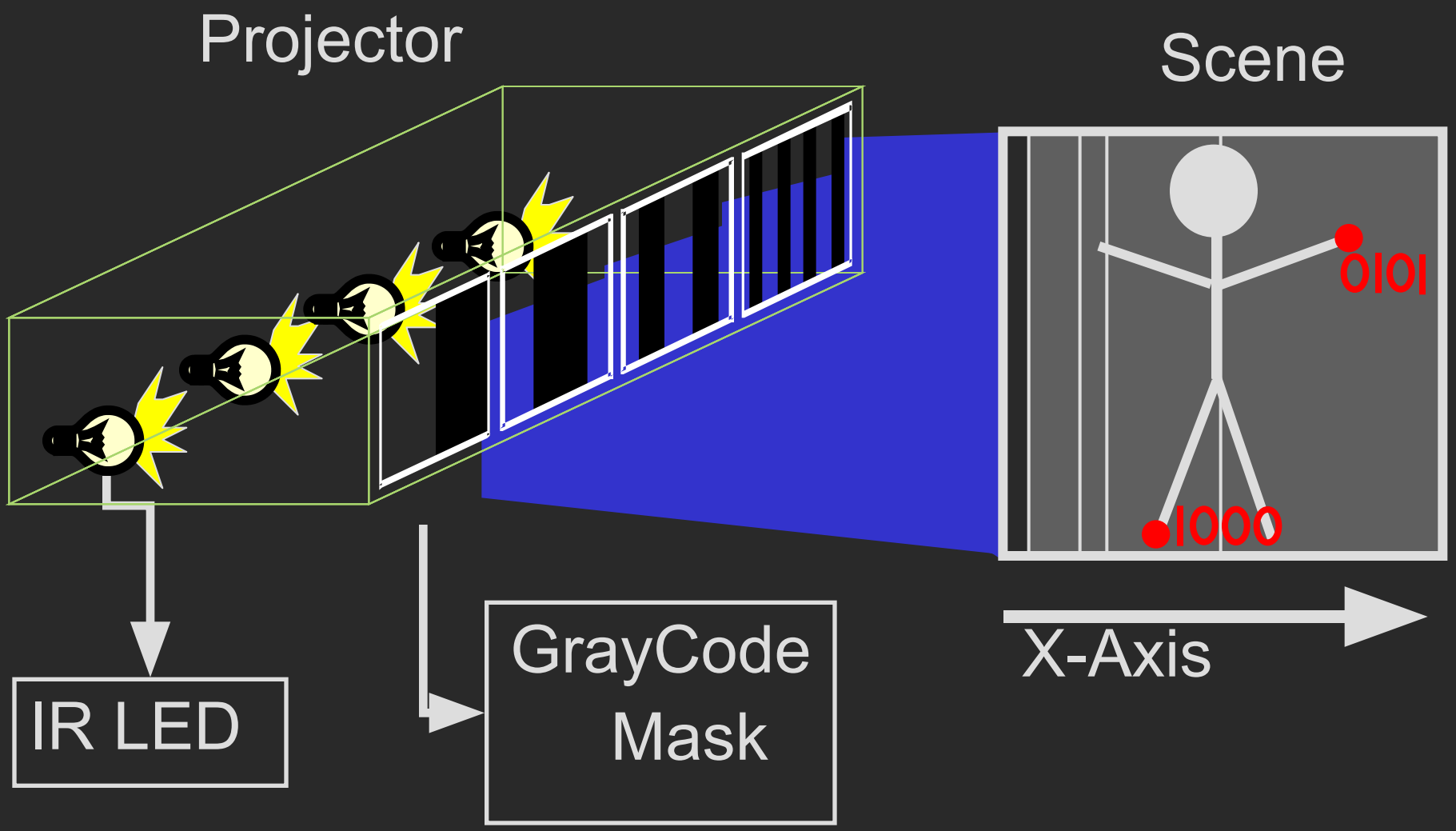


Fixed Masks + Blinking LEDs

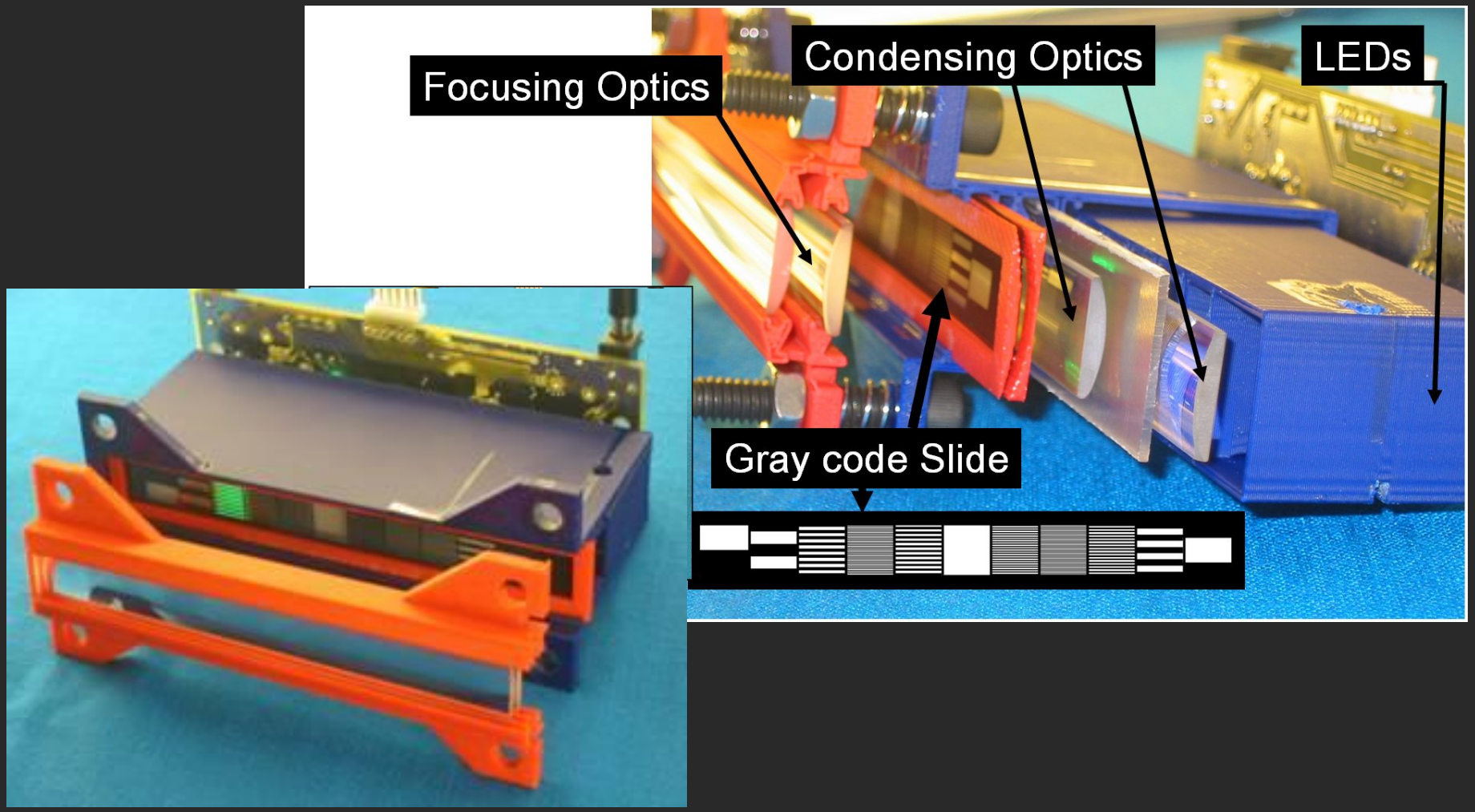

Tag
Beamer
pMSB-1
pMSB-2
MSB-1
MSB-2


Tag
Epipolar plane
Beamer
PMSB-1
PMSB-2
MSB-1
Warped MSB-1
Warped MSB-2
MSB-2

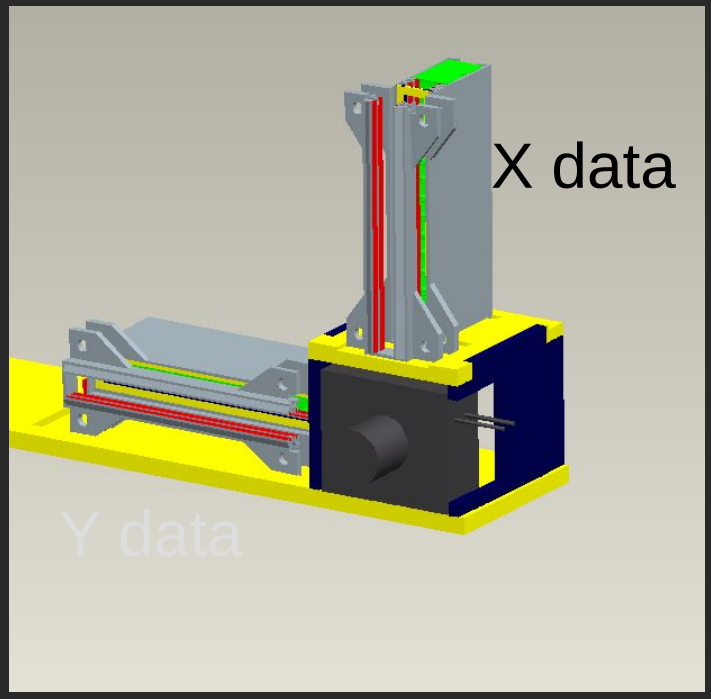
1D location tracking



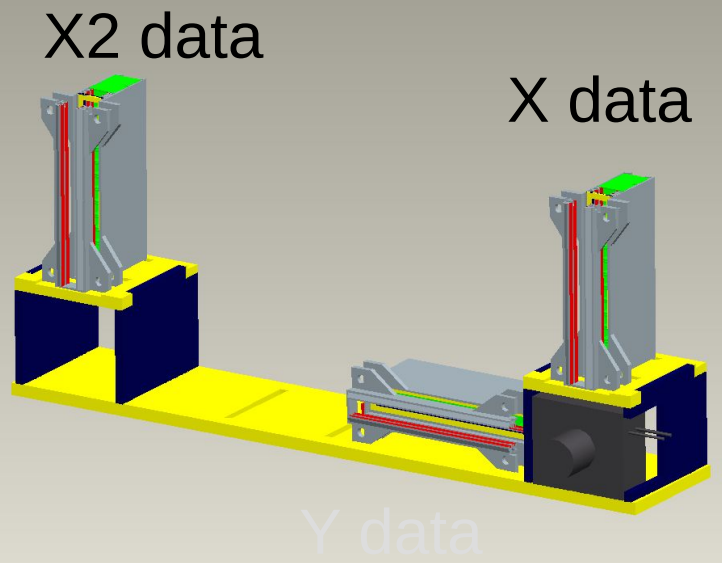
Inside of Projector



2D Location

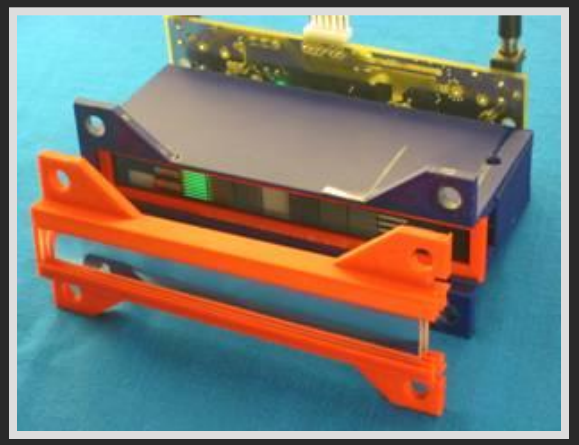


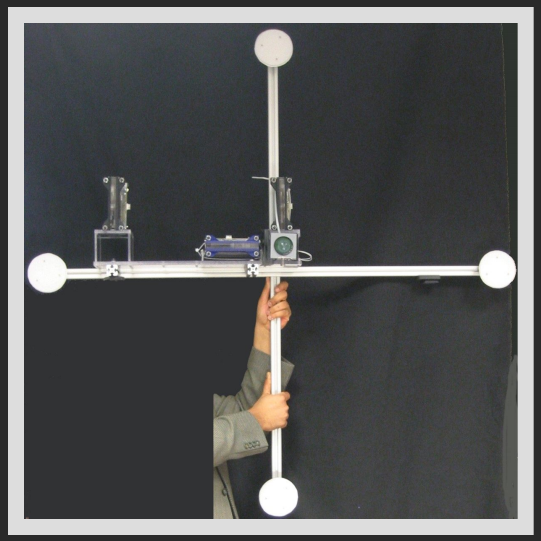
3D Location



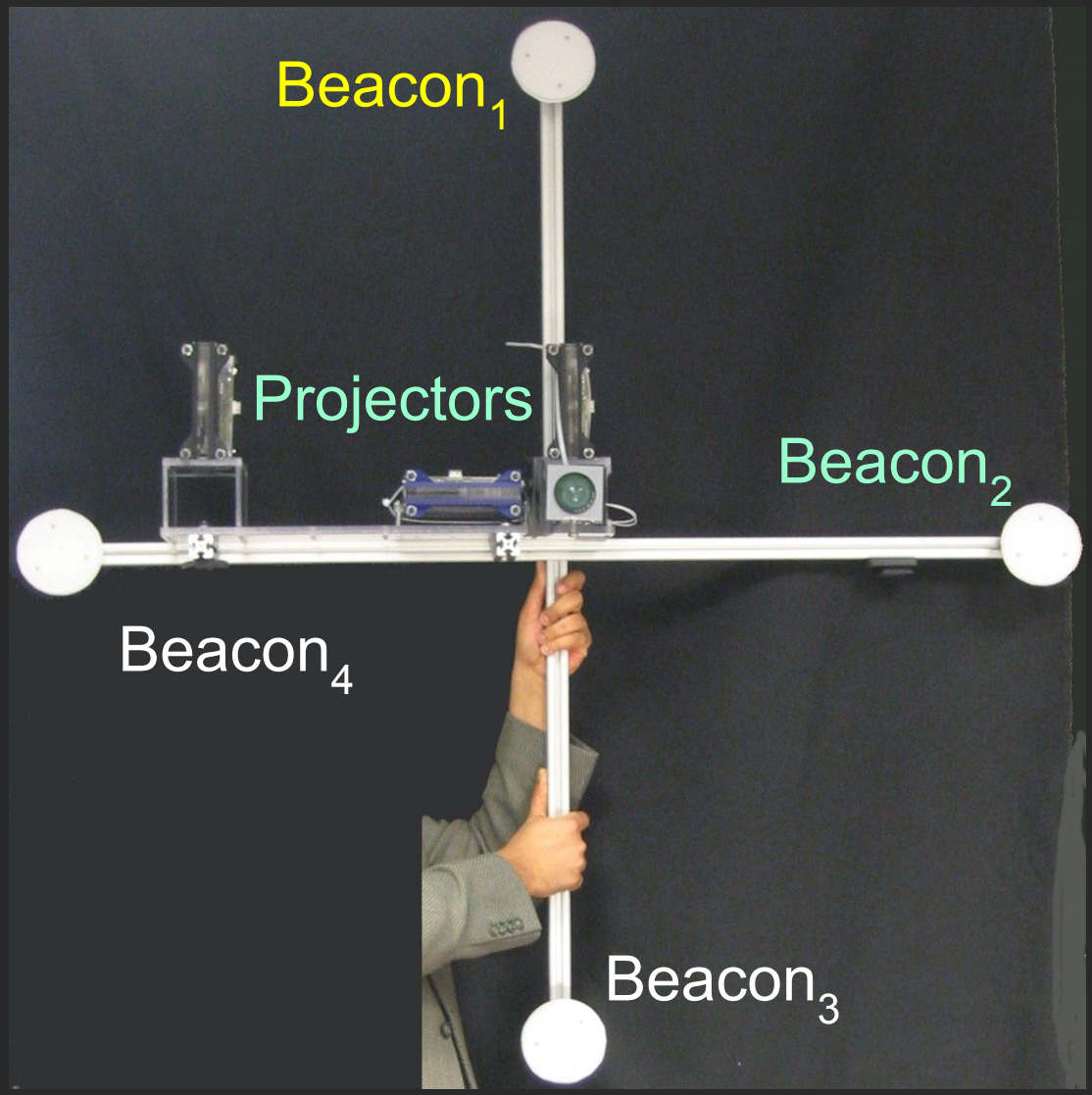
Prakash: Lighting-aware Mo-Cap

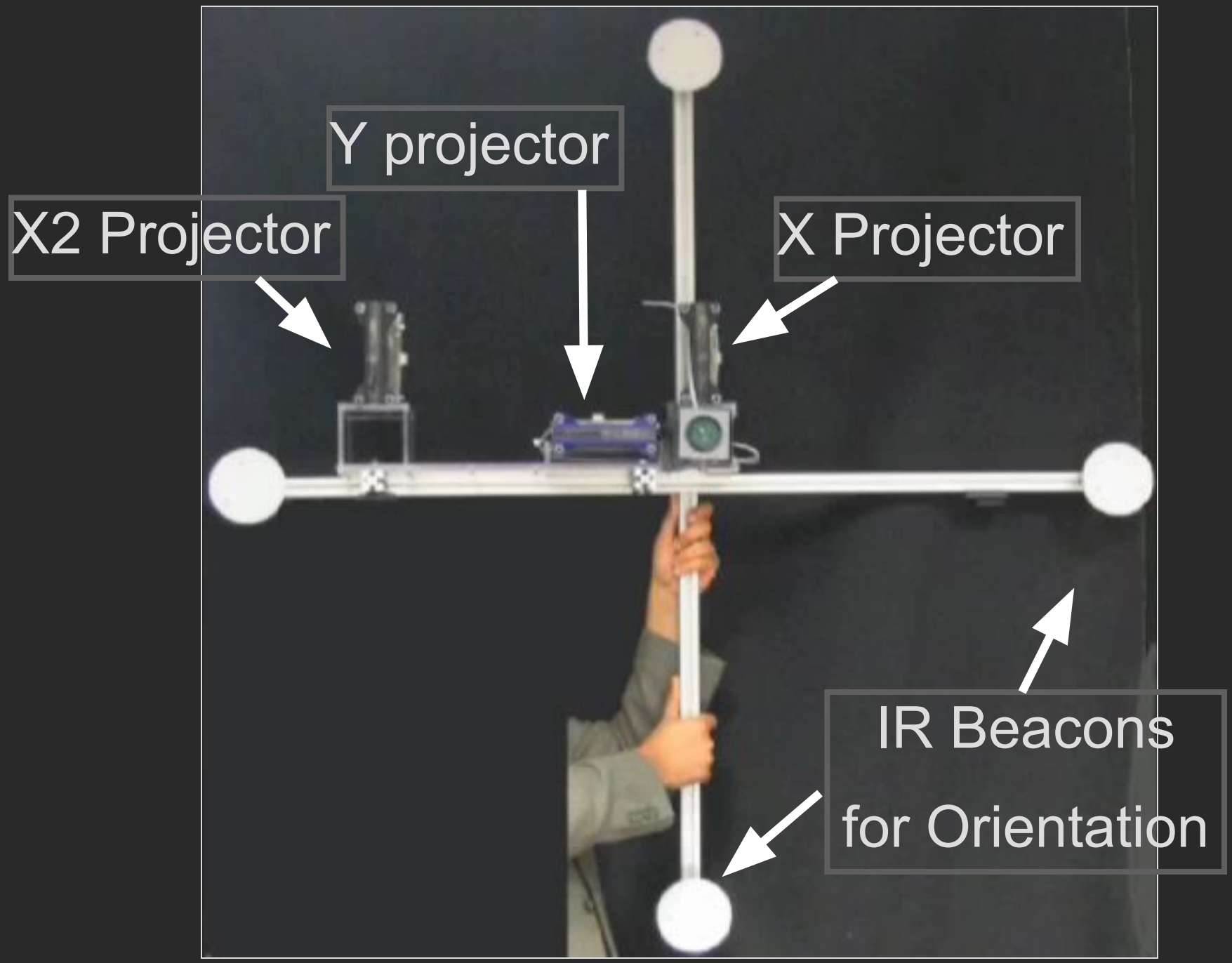
- Geometry via Space Labeling
  - Binary
    - High speed LED projector
    - 3D location
  - **Analog**
    - **Bright Beacons**
    - **Orientation**





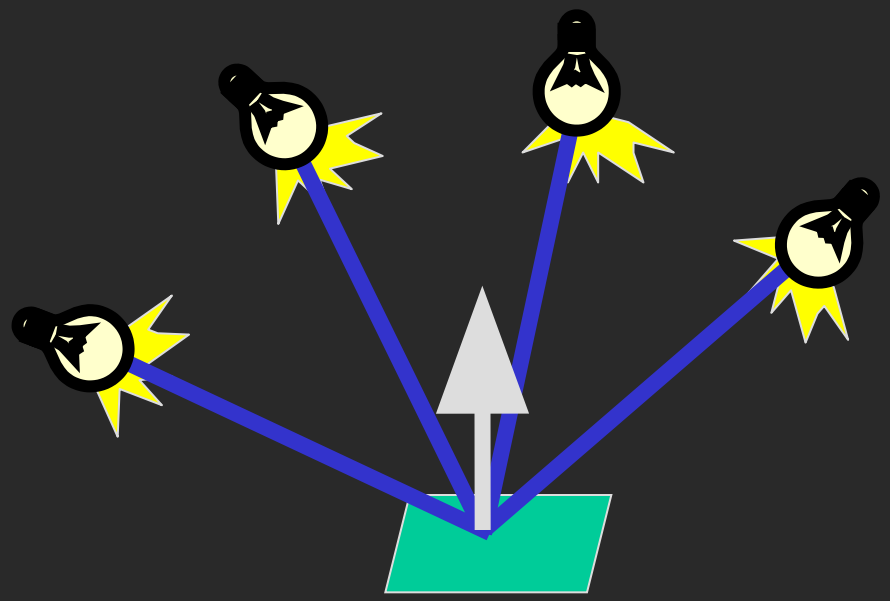
Analog Space Labeling




Y projector
X2 Projector
X Projector
IR Beacons
for Orientation

Orientation

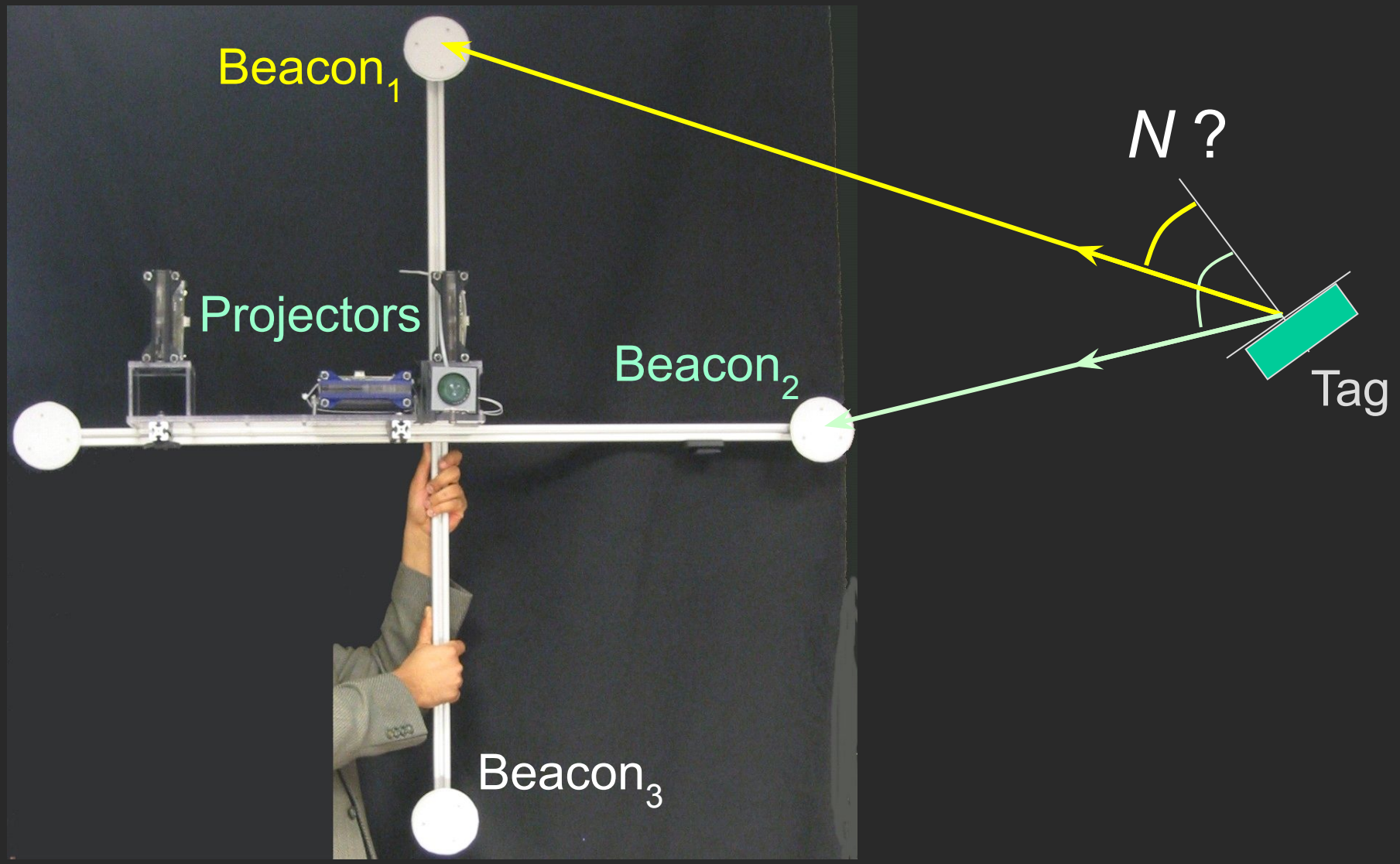
IR Beacons



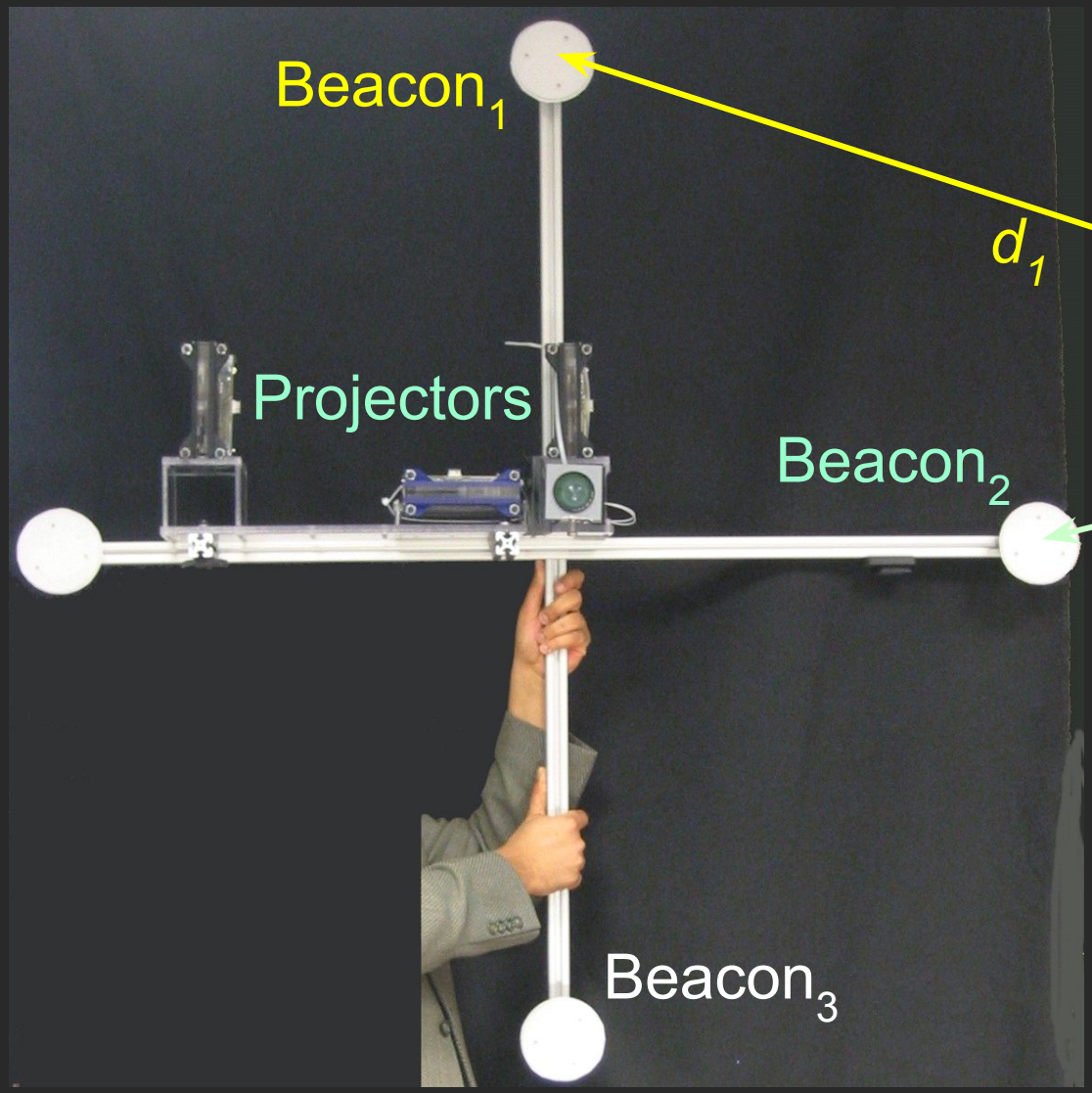
Photosensor

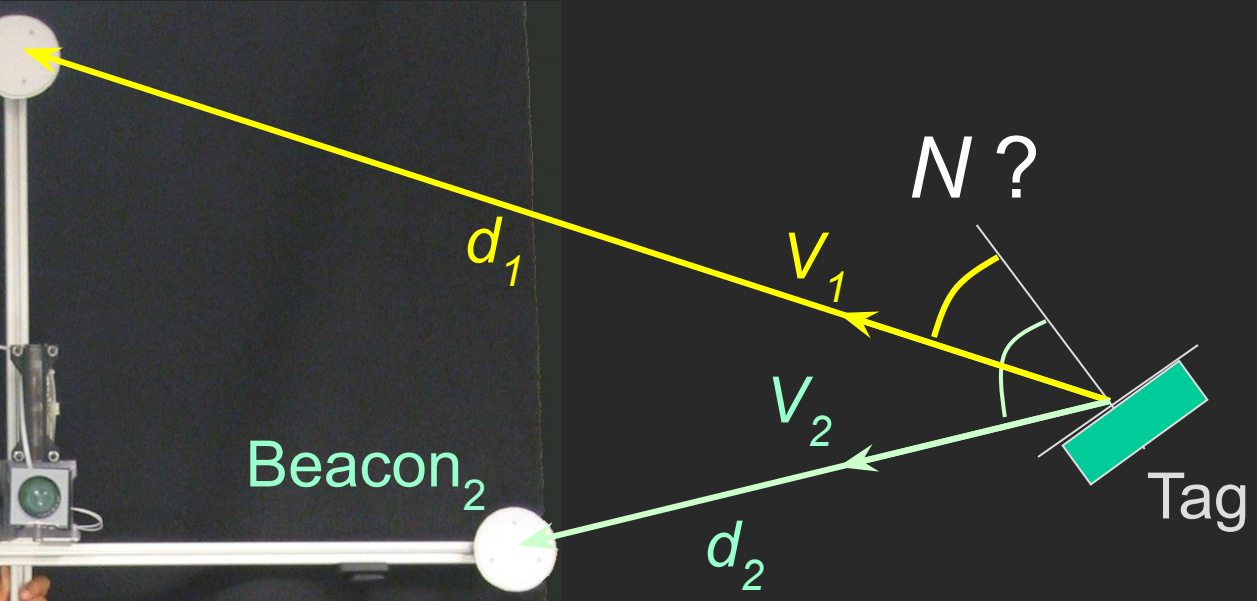
On Marker Tag

Analog Space Labeling



Analog Space Labeling





$$I \propto (V_i \bullet N)\frac{B_i}{d_i^2}$$

Cosine fall-off

Incident Illumination Color

On-set MoCap:
Location + Orientation + Incident Illumination

Limitations

- Occlusions and Accuracy
  - Multiple surround transmitters
- Strong Ambient Light
  - High frequency (455Khz) Modulation
- Inter-reflections
  - Binary optical communication

- Wires on Tags
  - Batteries + cables
  - Limited Wireless Bandwidth
    - Compression on aggregate data
- Very Fast Motion
  - Simultaneity assumption

Tracking Specular Object

Tracking behind Coca Cola

System Specifications

- Location tracking in 2D: 500 Hz
- Location+Orientation+Illum: 124 Hz

- Location:
  - FoV: 27 degrees
  - Angular resolution 0.1 degrees
  - Accuracy ~5mm at 3 meters
- Orientation:
  - Resolution ~1 degree at 3 meters

- Emerging Technology Demo
  - 200,000 Hz Multi-LED Projector
  - Location precision 100 micrometer
  - Camera tracking with imperceptible markers
  - All week
- Sketch (Later today)
  - More details
  - Rendering techniques
  - Tuesday 3:30pm, ‘Is it real’, Room 1AB

Prakash: Lighting Aware Optical Mo-Cap

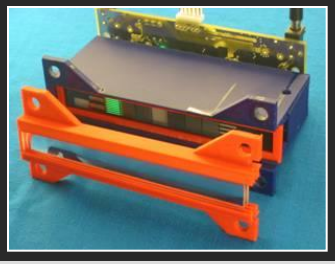
Device	Projector + Photosensor	Camera + Markers
Params	Location, Orientation, Illum	Location
Settings	Natural Light + Hidden Tags	Controlled Light + Visible, High contrast Markers
# of Tags	Unlimited + Unique Id	Limited + MarkerSwap
Speed	Unlimited with Optical comm comps	Limited with camera fps
Cost	Low Open-loop projectors Current: Projector/Tag=$100	High High bandwidth camera Current Camera: $10K

END

Related Work

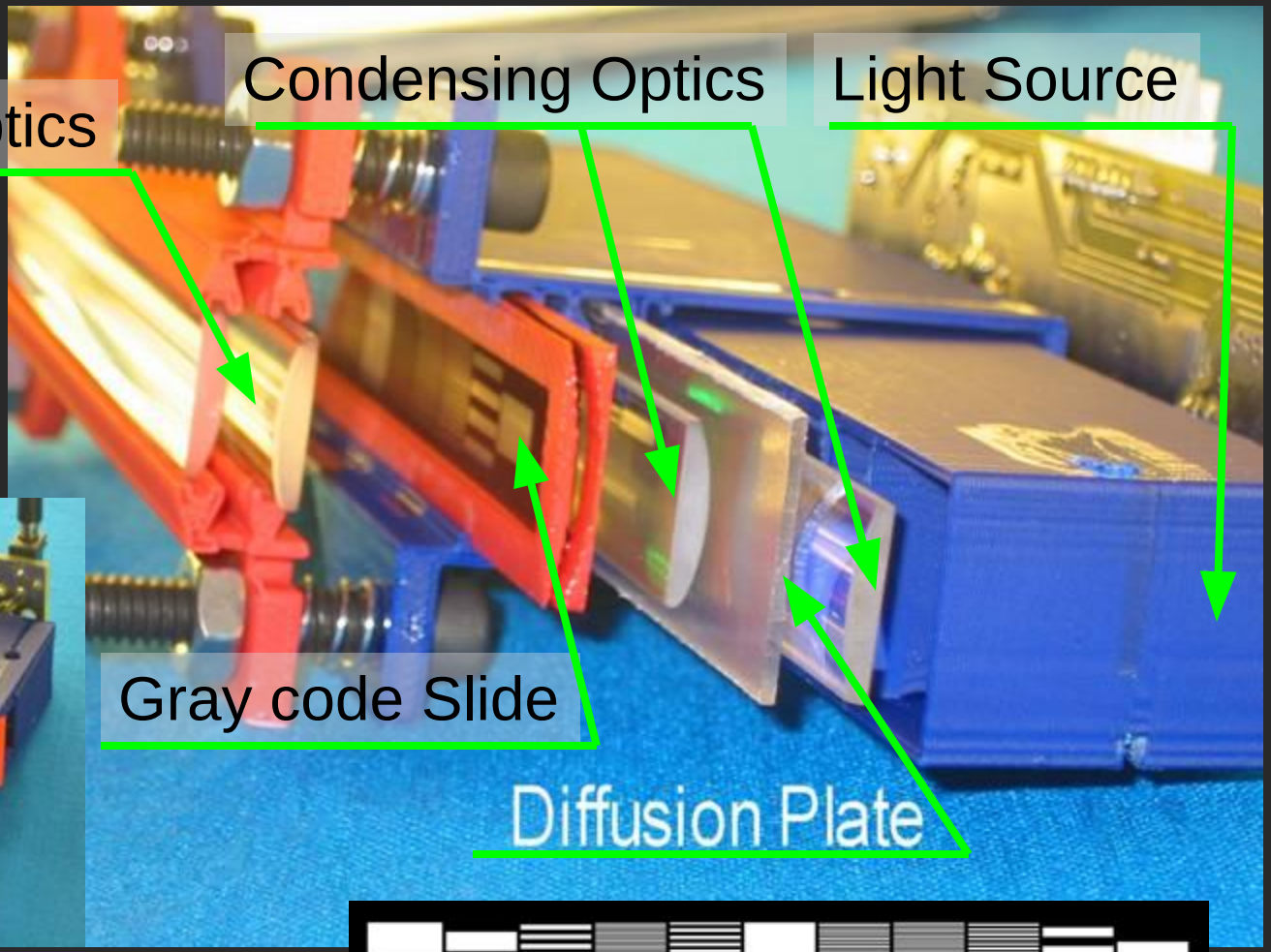
- Camera Based systems [ViconPeak 2006; Optotrak 2007; PhaseSpace2005]
  - Expensive high speed cameras
- Systems using Photosensors [Indoor GPS 2004; HiBall 1997]
  - Low framerate or challenging setup
- Magnetic/Acoustic Based Systems [F.H. Raab et al. 1979]
  - Interference, drift
- Inertial Tracking (Gyro / Compass) [G. Welch 1995]
  - Drift

Inverse Optical Mo-Cap

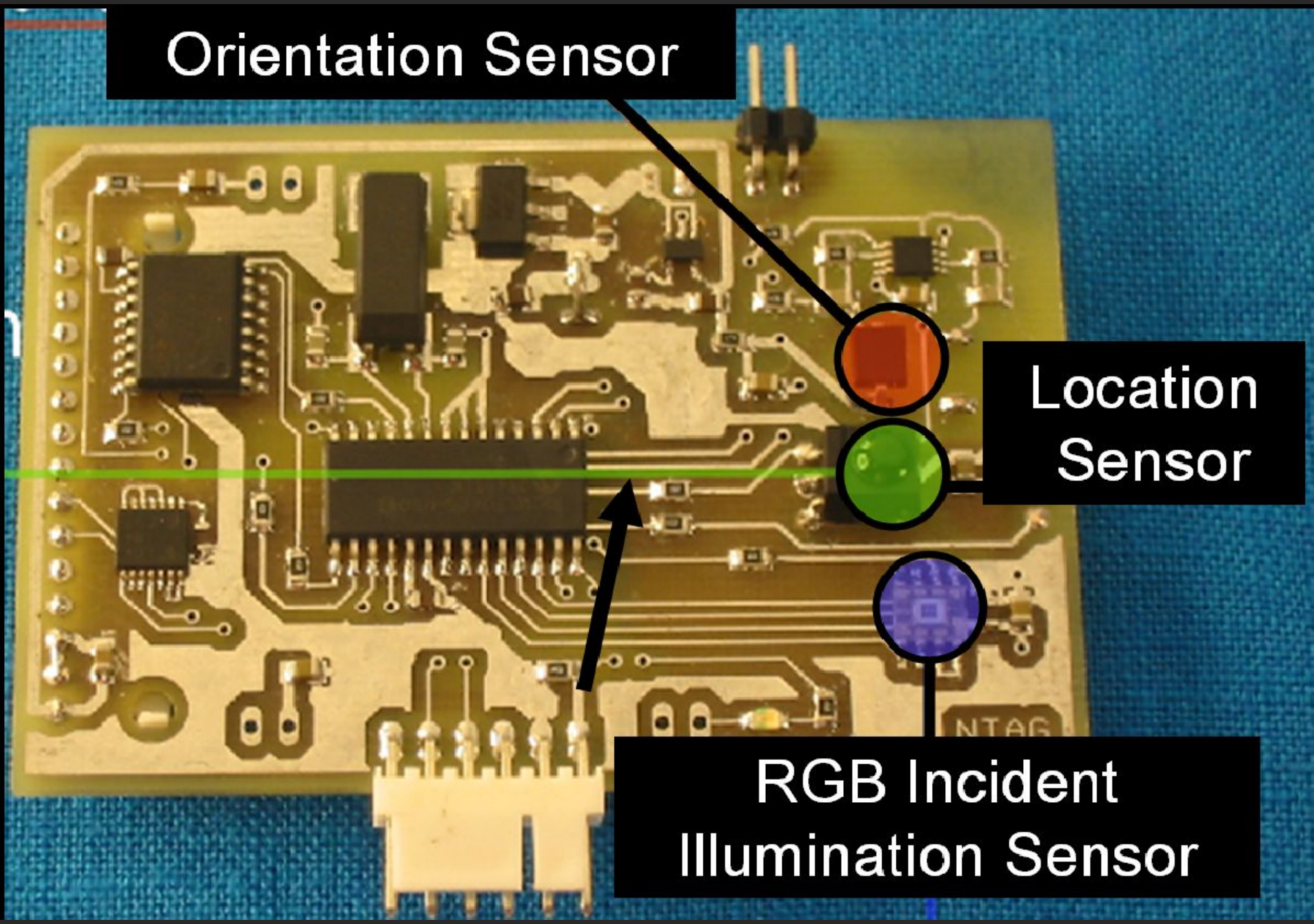


Device	High Speed Projector + Photosensing Markers	High Speed Camera + Reflecting/Emitting Markers
Params	Location, Orientation, Illum	Location
Settings	Natural Settings Ambient Light Outdoors, Stage lighting Imperceptible tags Hidden under wardrobe	Controlled Lighting Visible, High contrast Markers
#of Tags	Unlimited Space Labeling Unique Id	Limited No Unique Id Marker swapping
Speed	Virtually unlimited Optical comm comps	Limited Special high fps camera
Cost	Low Open-loop projectors Current: Projector/Tag=$100	High High bandwidth camera Current Camera: $10K

Inside of Projector



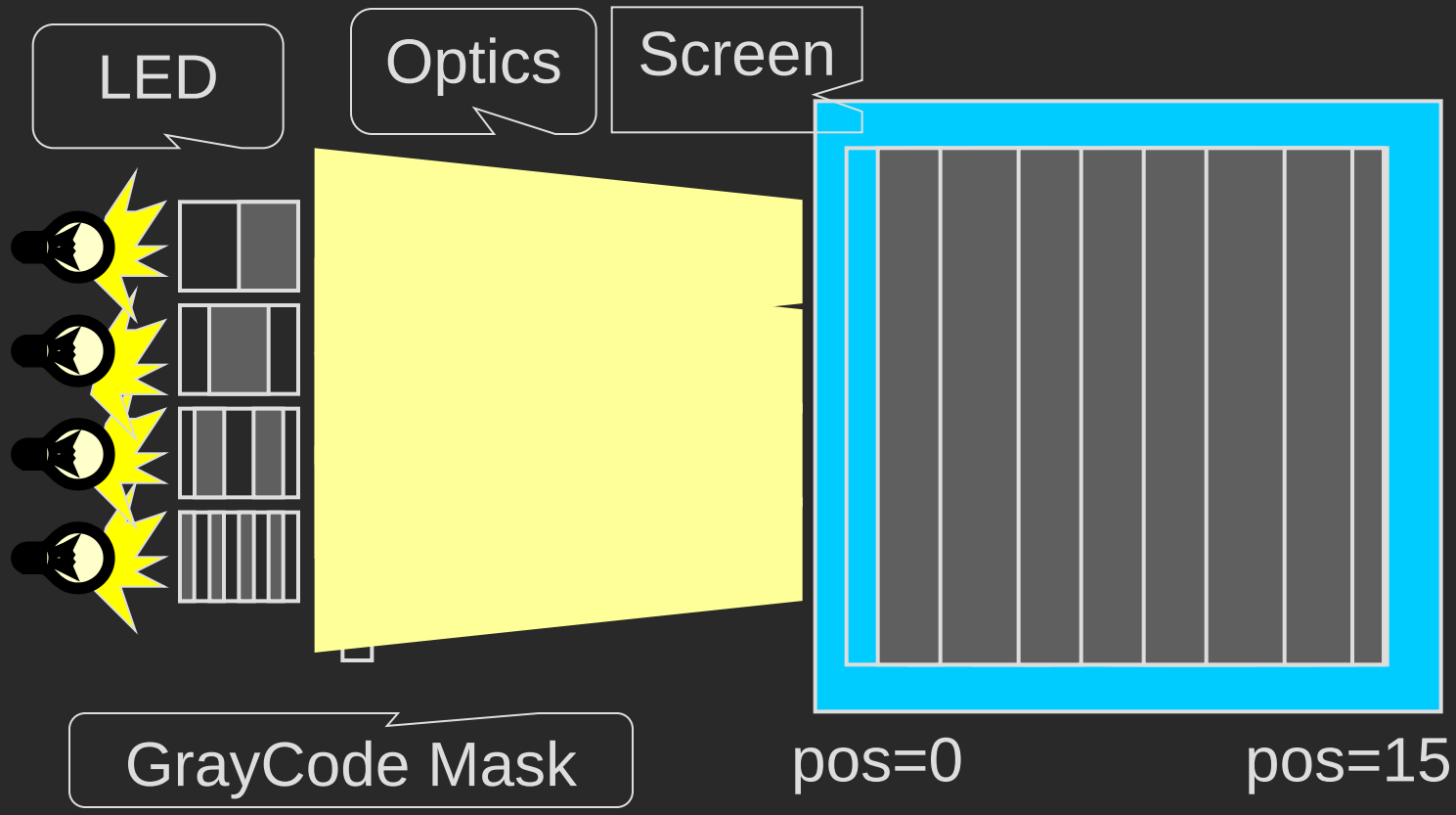
The Gray code pattern


Orientation Sensor
Location Sensor
RGB Incident Illumination Sensor

Optical Mo-Cap

- High-speed Cameras
  - Controlled Settings
    - Visible retroreflective markers/LEDs
    - High contrast clothing
    - Controlled lighting
  - No unique Id
    - Marker-swapping/reacquisition issues
    - Cleanup software
  - Expensive
    - High bandwidth
    - Limited by camera frame rate
- Non-optical Mo-Cap
    - Drift/Global distortions
    - Difficult for video overlay

Labeling Space



1 LED for 1 Bit pattern