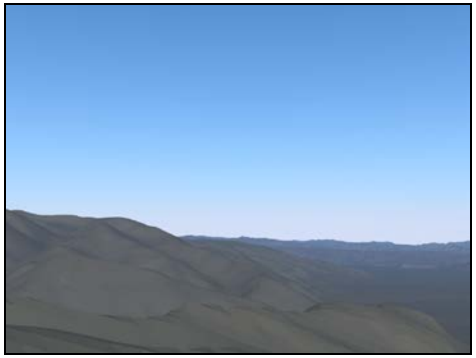
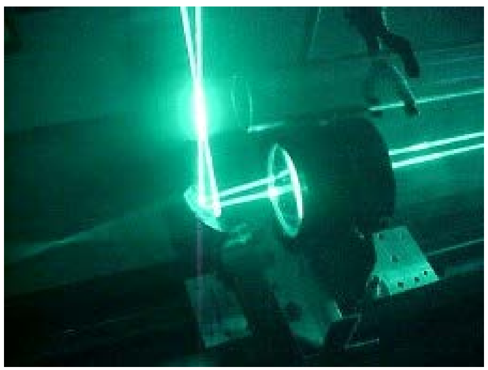
Lighting and Shadows: Applications

Lecture #10

Thanks to Li Zhang, Yoav Schechner, Steve Seitz, Bouguet, Perona, Ravi Ramamoorthi

Is there a unified representation for light sources?

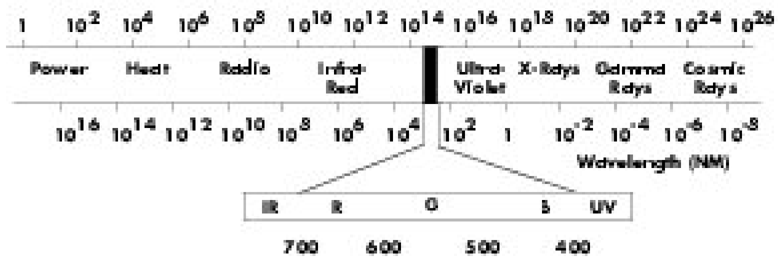
How do we compare the light from a street lamp to that from an overcast sky?

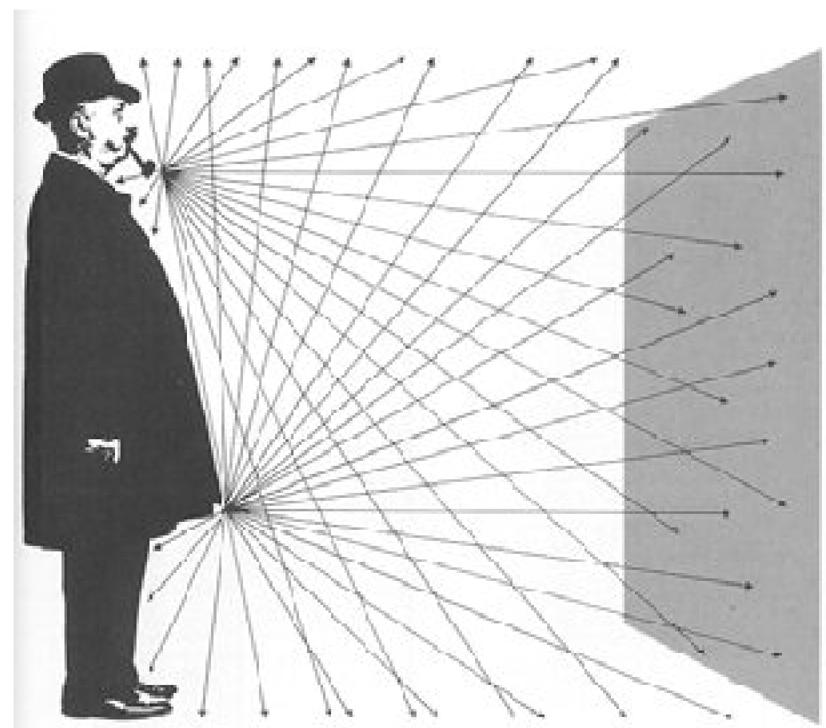
It is important to unify source representation so that algorithms may be developed for all sources instead of one per type of source.

Consider the SPACE of LIGHT RAYS!

The Light Field

Electromagnetic waves and power spectrum





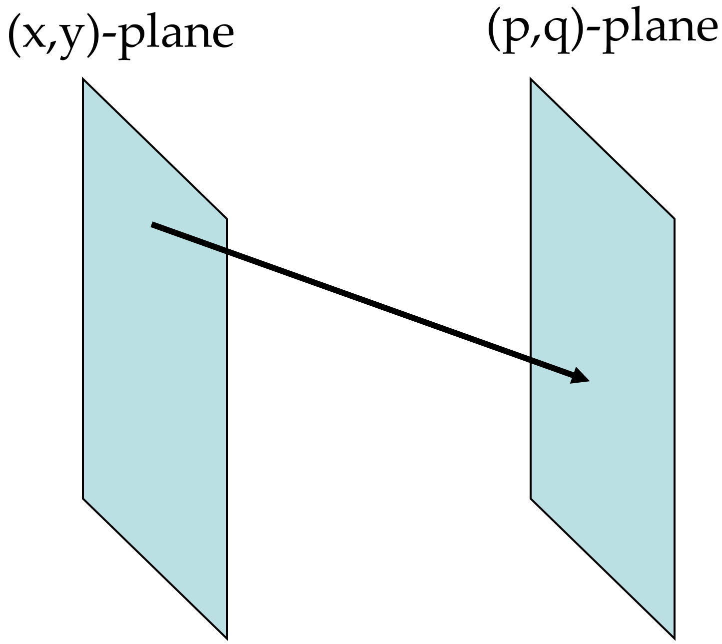
Ignore polarization

Ignore photons

Spatial distribution

From London and Upton

4D Hypercube of Rays



- Assumes vacuum (no absorption or scattering)
- No fluorescence, phosphorescence

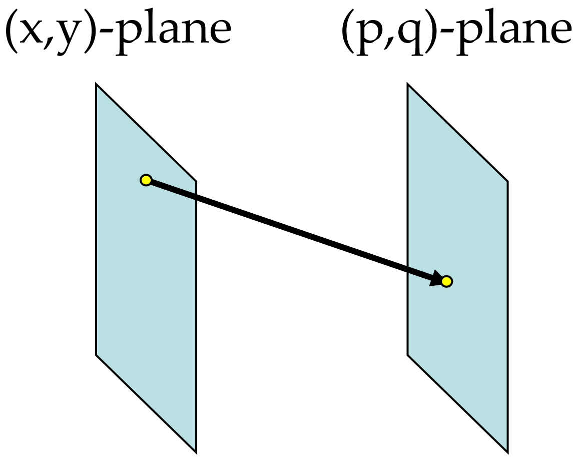
$$\mathcal{M}_{src} \equiv \{ (x,y,p,q) : x \in [-\frac{h_x}{2}, \frac{h_x}{2}],$$

$$y \in [-\frac{h_y}{2}, \frac{h_y}{2}], p \in [-\frac{h_p}{2}, \frac{h_p}{2}], q \in [-\frac{h_q}{2}, \frac{h_q}{2}] \}.$$

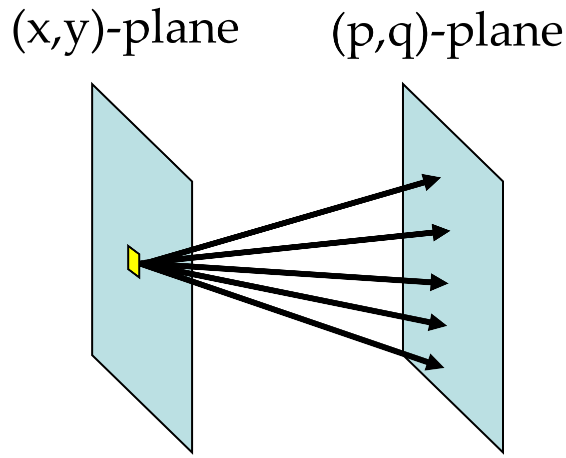
Langer and Zucker, CVPR 97

Representation of Sources

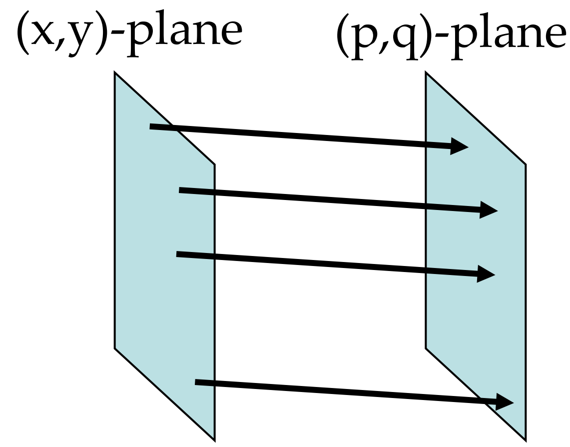
Langer and Zucker, CVPR 97



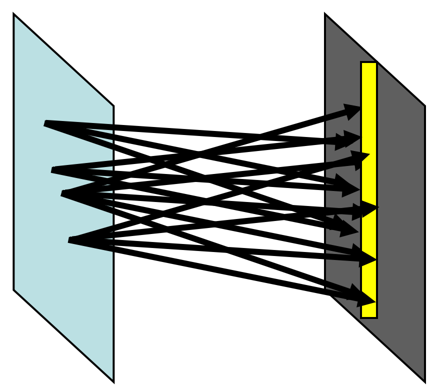
Laser beam – 0D



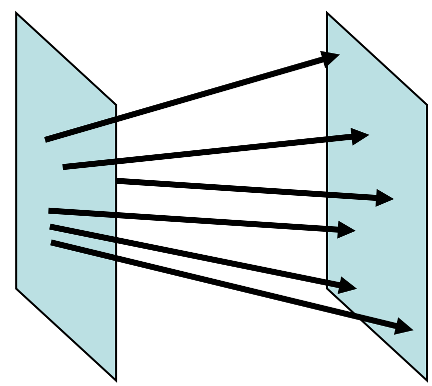
Point source – 2D



Distant Source (Sun) – 2D



Area source (Sky) with
a crack in the door – 3D



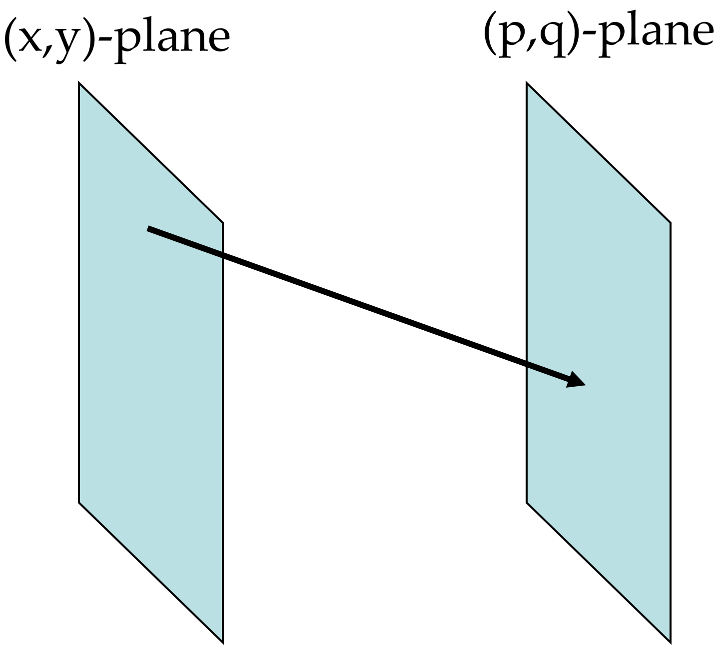
Area source (Sky) with
door completely open – 4D

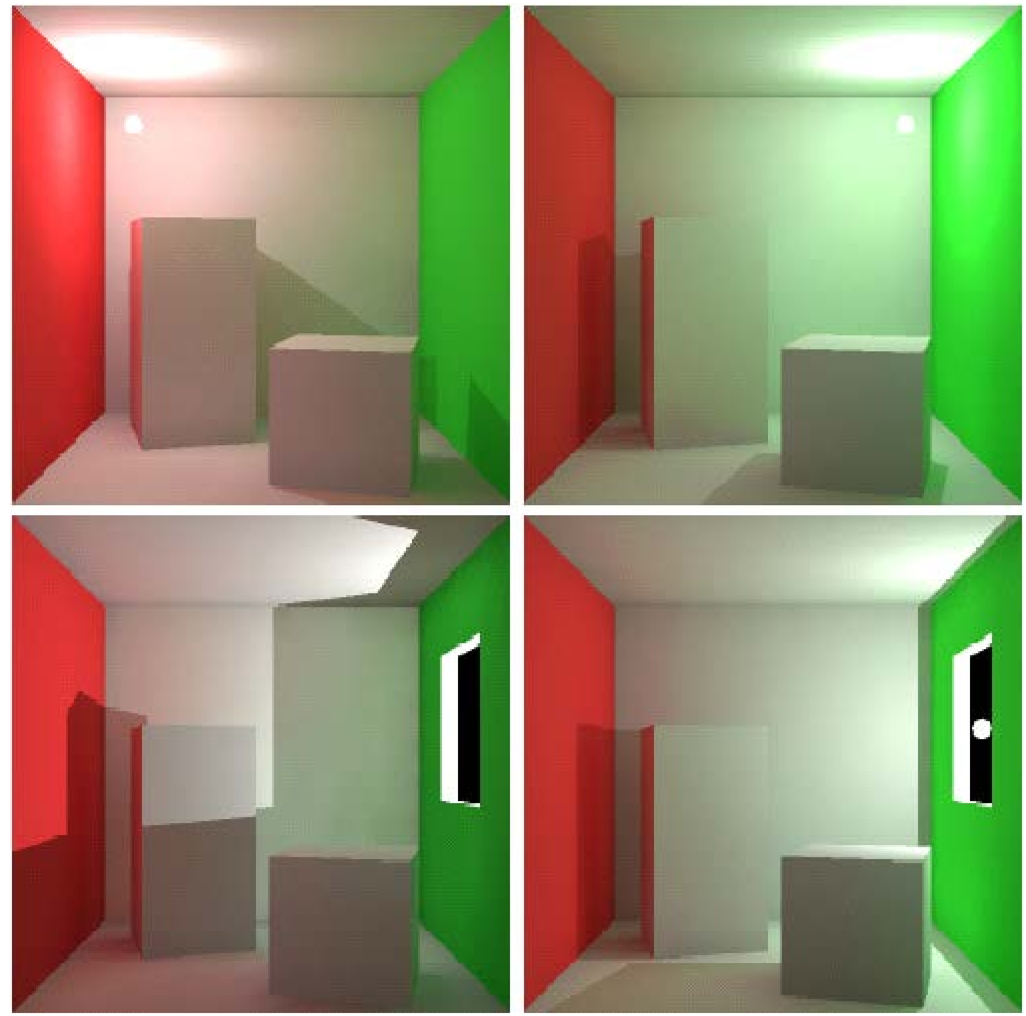
Corners of the 4D Hypercube

Non-ideal example	*Ideal model*	h_x	h_y	h_p	h_q	dimension
overcast sky	uniform source	∞	∞	∞	∞	4
Cyberware^{TM} scanner		∞	∞	∞	0	3
		∞	∞	0	∞	
fluorescent tube	linear source	∞	0	∞	∞	3
		0	∞	∞	∞	
sunlight	point source at infinity	∞	∞	0	0	2
	uniform distribution of rays in a plane	∞	0	∞	0	2
		0	∞	0	∞	
louvered linear source (see text)	fan of rays perpendicular to a linear source	∞	0	0	∞	2
		0	∞	∞	0	
small panel light	point source	0	0	∞	∞	2
sunlight through crack in doorway	parallel rays in a plane	∞	0	0	0	1
		0	∞	0	0	
rotating spotlight	fan of rays	0	0	0	∞	1
		0	0	∞	0	
spotlight or laser	single ray	0	0	0	0	0

Langer and Zucker, CVPR 97

Examples of sources





What is a Light Source?

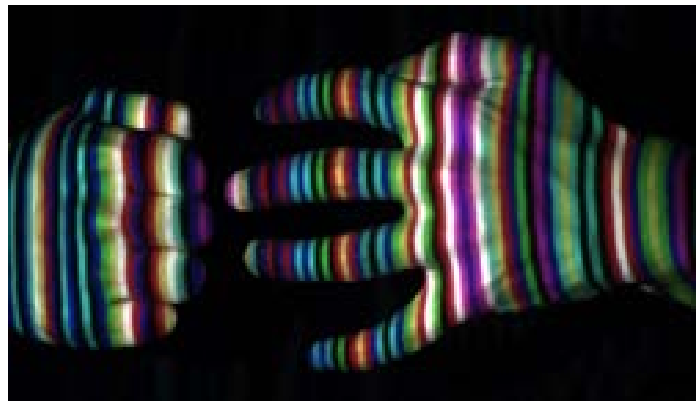
Is sky a source? If so, why not a white piece of paper?

Is a translucent object a source?

How to differentiate between source rays and non-source rays?

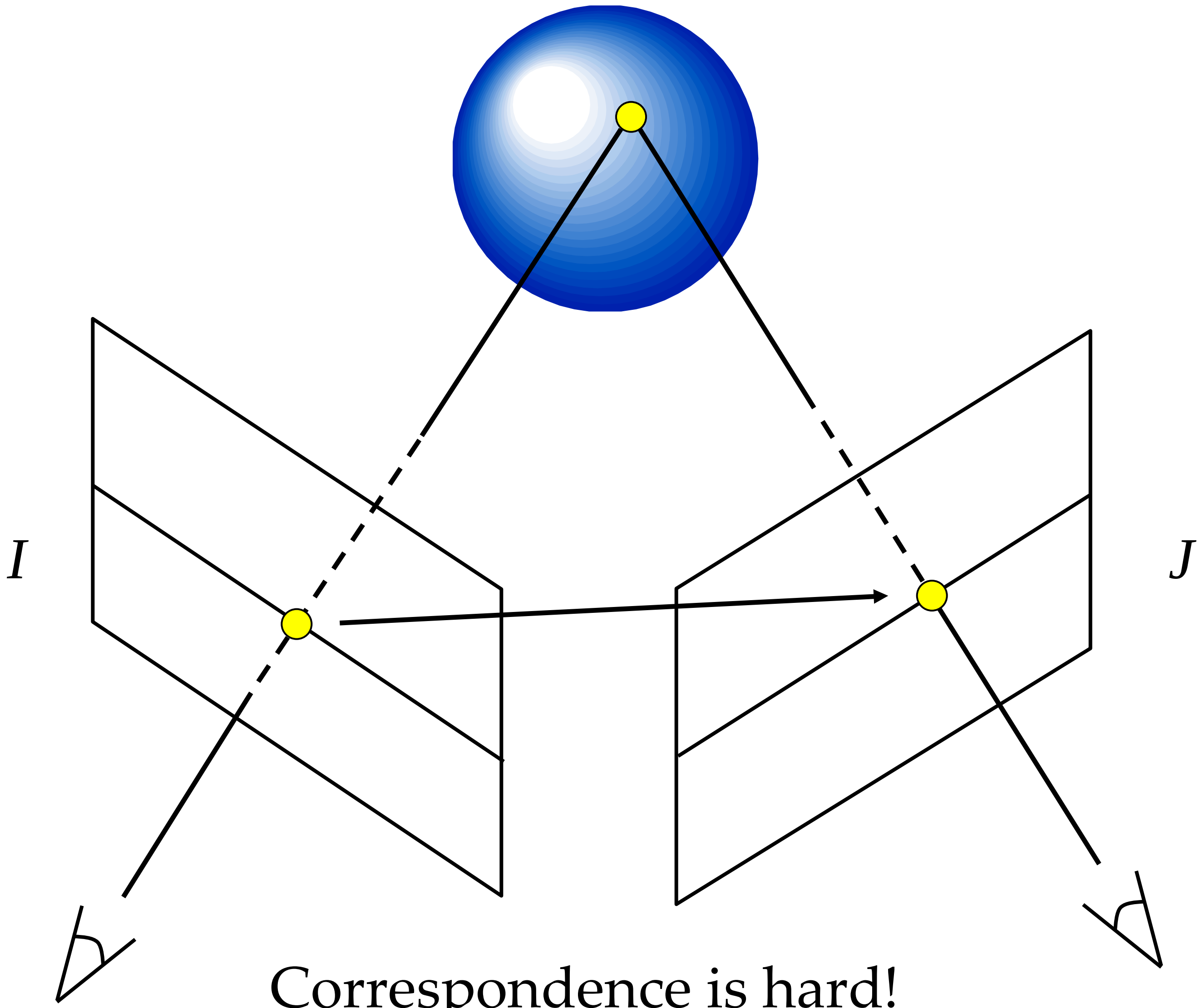
Define a minimum set of absorbants at the ends of rays so that the whole ray space is dark.

Structured Light

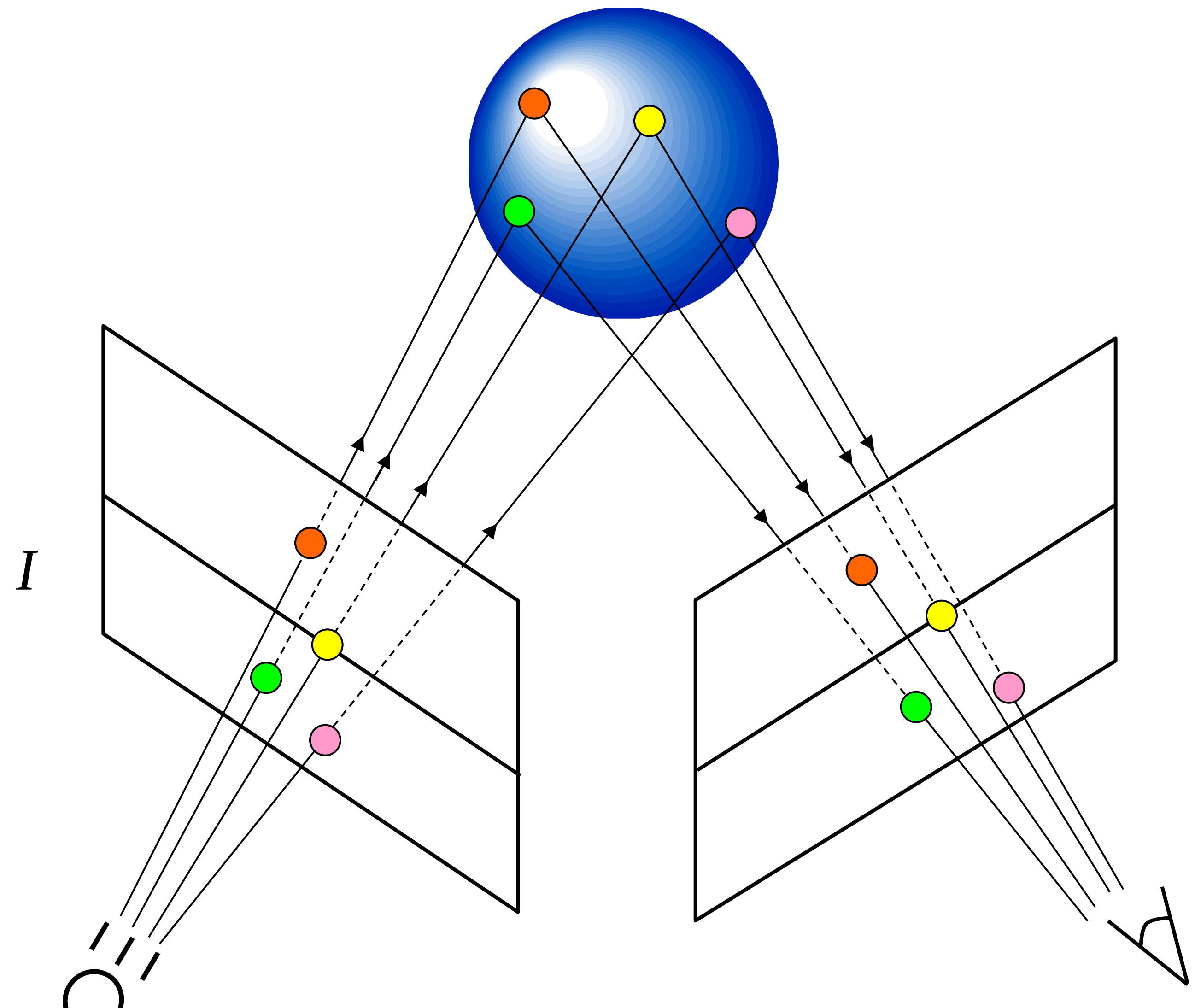

- Any spatio-temporal pattern of light projected on a surface (or volume).
- Cleverly illuminate the scene to extract scene properties (eg., 3D).
- Avoids problems of 3D estimation in scenes with complex texture/BRDFs.
- Very popular in vision and successful in industrial applications (parts assembly, inspection, etc).

Stereo Triangulation



Correspondence is hard!

Structured Light Triangulation

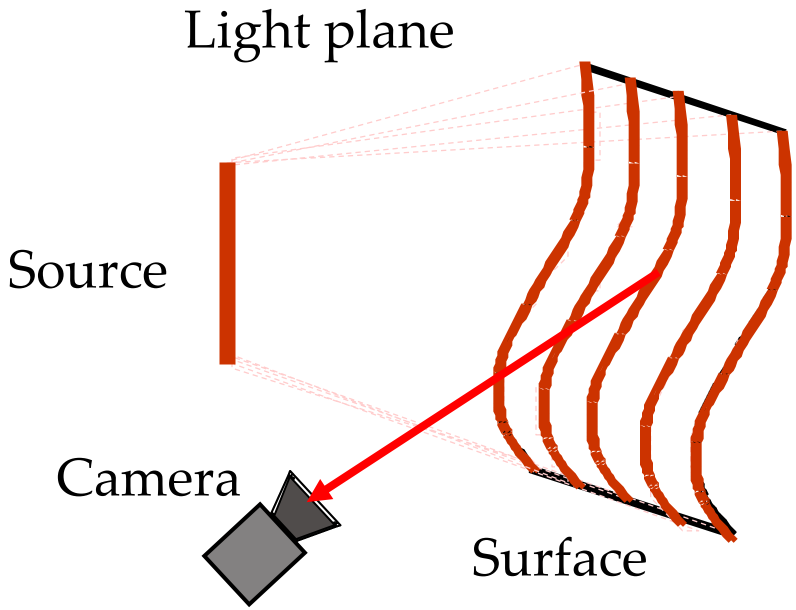


Correspondence becomes easier!

Light Stripe Scanning

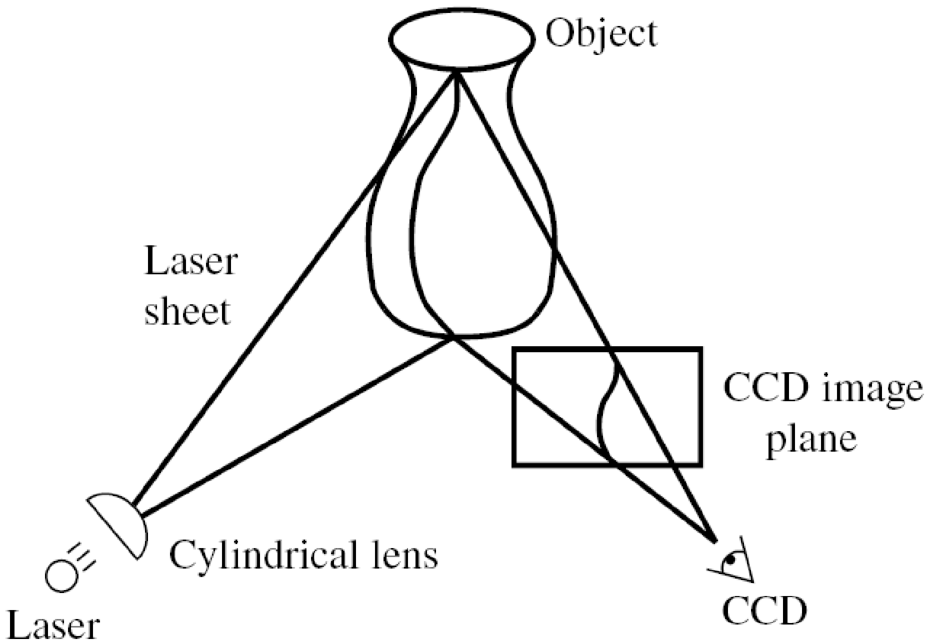
- Single light stripe
- Spatially gray coded light striping
- Spatially Color coded light striping
- Spatio-temporally coded light striping

Light Stripe Scanning – Single Stripe



Need lots of Images

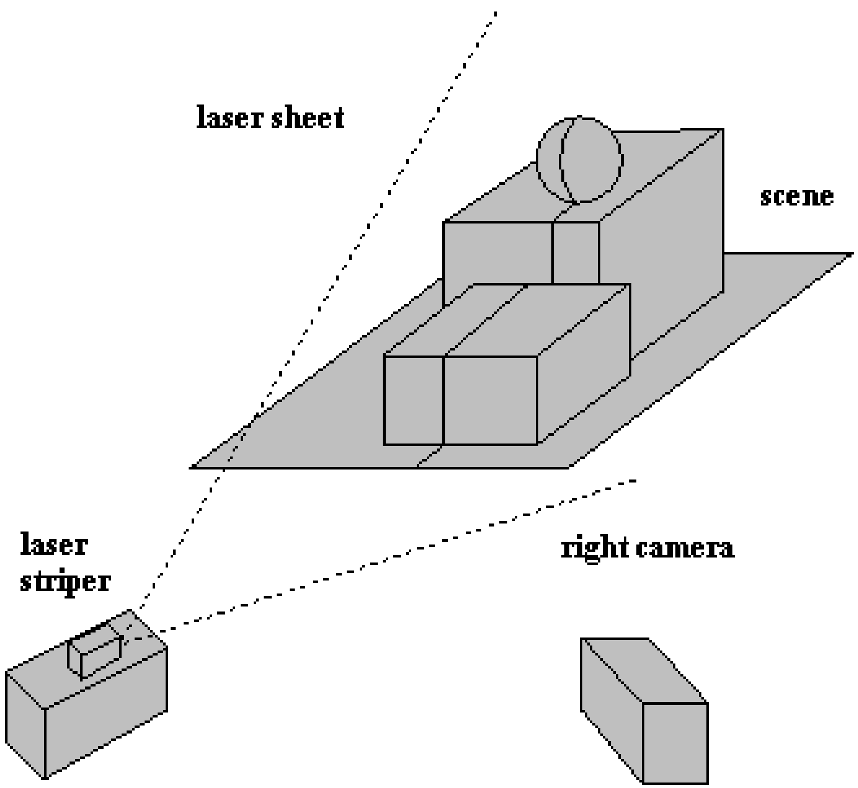
Laser scanner

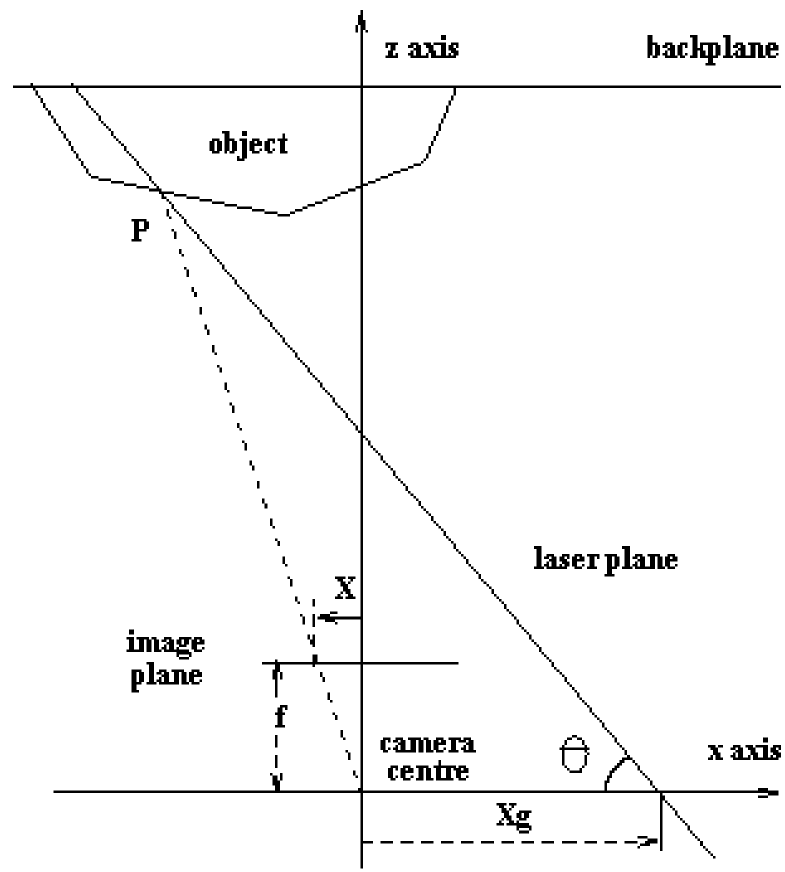


Cyberware® face and head scanner

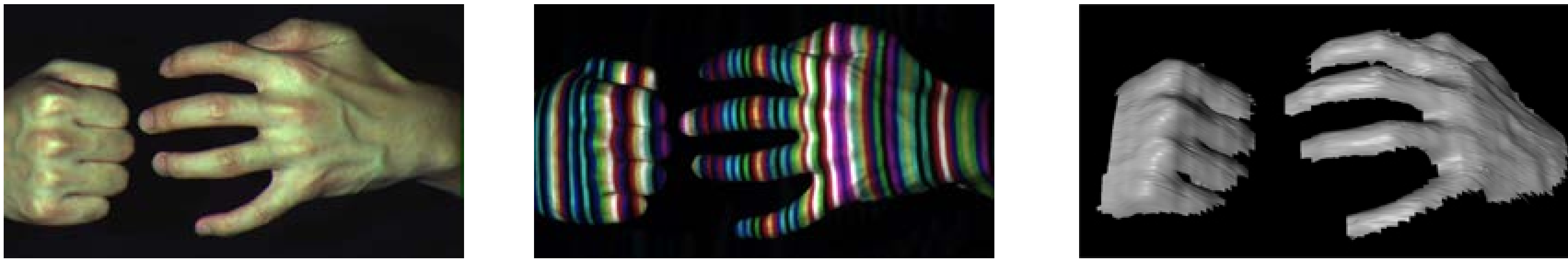
+ very accurate < 0.01 mm
– more than 10sec per scan

Triangulation

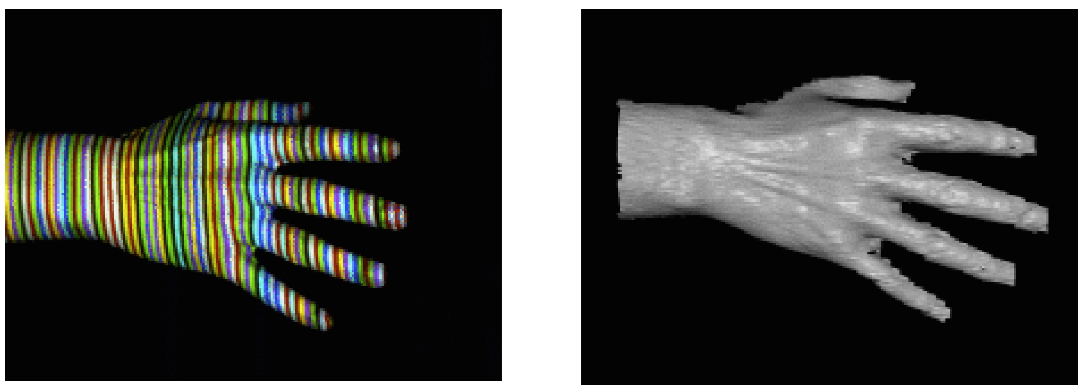




Structured Light – More complex patterns



Works despite complex appearances

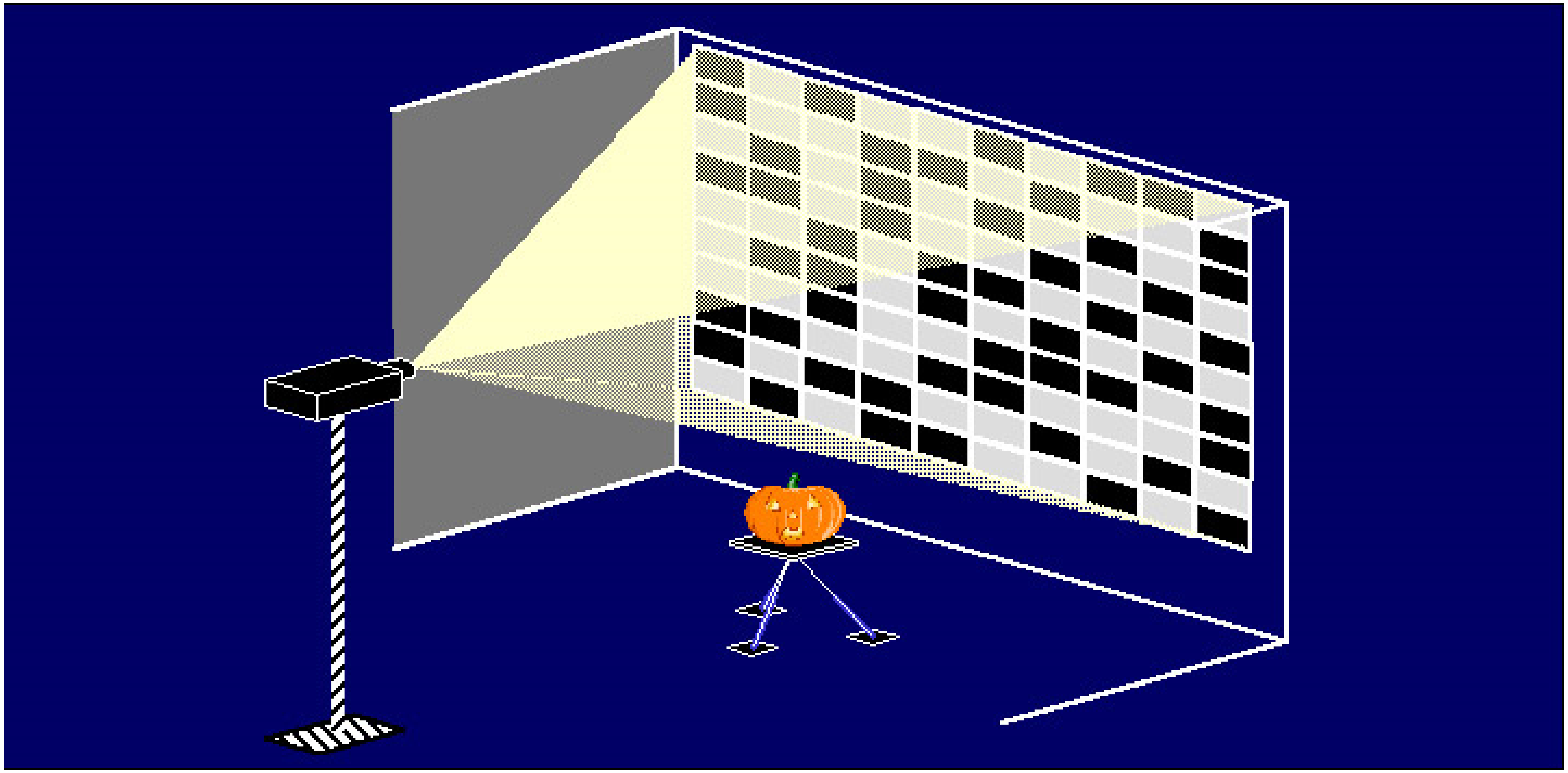


Works in real-time and on dynamic scenes

Need very few images

Zhang et al

Illumination Multiplexing



Easier setup to capture several lighting directions.

Illumination Multiplexing

$$\begin{bmatrix} \hat{i}_1^{\text{single}} \\ \hat{i}_2^{\text{single}} \\ \hat{i}_3^{\text{single}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

$$\begin{bmatrix} a_{1,2} \\ a_{2,3} \\ a_{1,3} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix}$$

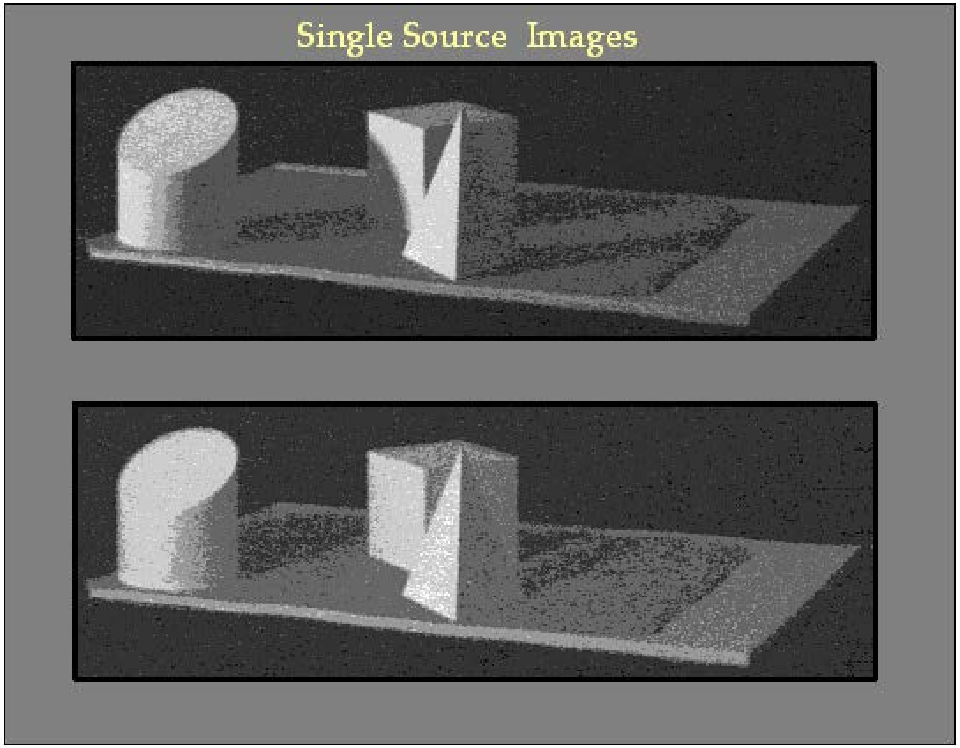
Illumination De-Multiplexing

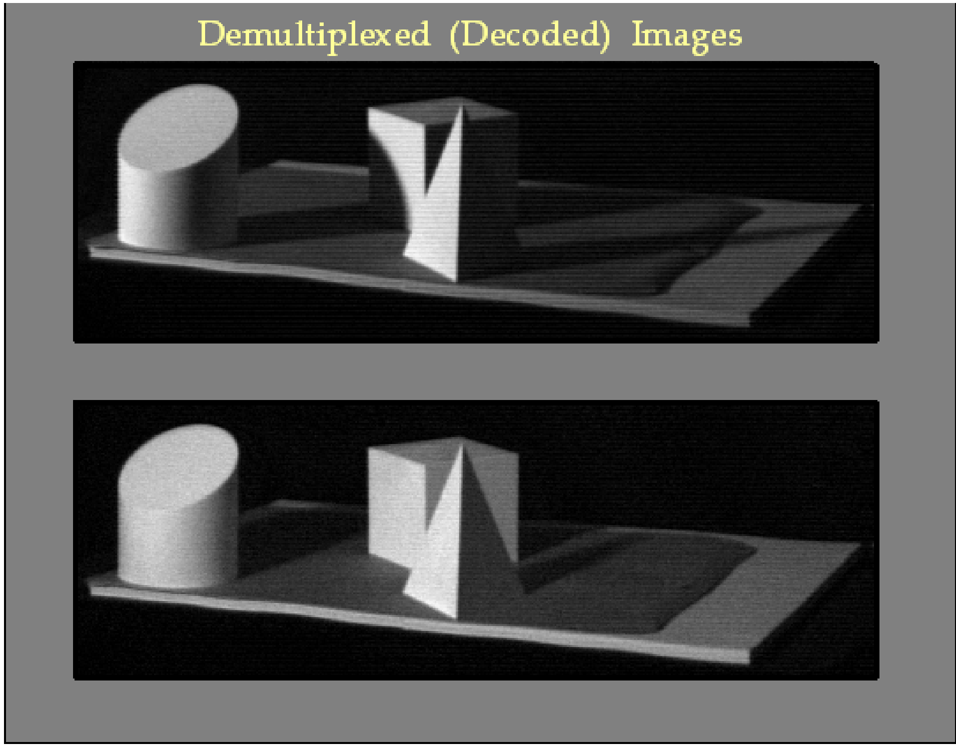
$$\begin{bmatrix} \hat{i}_1^{\text{single}} \\ \hat{i}_2^{\text{single}} \\ \hat{i}_3^{\text{single}} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

$$\begin{bmatrix} a_{1,2} \\ a_{2,3} \\ a_{1,3} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix}$$

$$\begin{bmatrix} \hat{i}_1^{\text{decoded}} \\ \hat{i}_2^{\text{decoded}} \\ \hat{i}_3^{\text{decoded}} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \end{bmatrix} \begin{bmatrix} a_{1,2} \\ a_{2,3} \\ a_{1,3} \end{bmatrix}$$

Illumination De-Multiplexing





Better signal to noise ratio using Hadamard Codes:

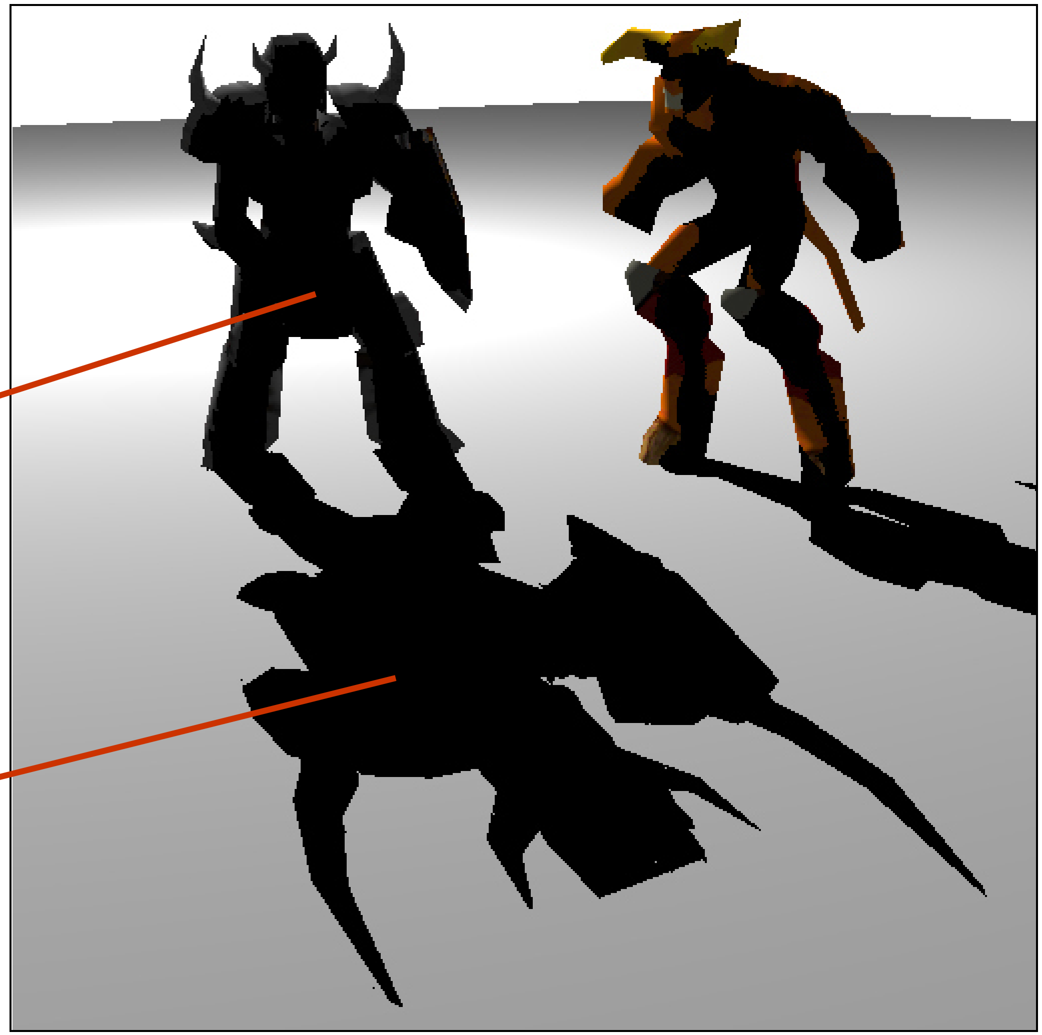
$$\frac{\mathrm{SNR}_{\mathrm{Hadamard}}}{\mathrm{SNR}_{\mathrm{single}}} = \frac{\sqrt{n} + (1/\sqrt{n})}{2} \approx \frac{\sqrt{n}}{2}$$

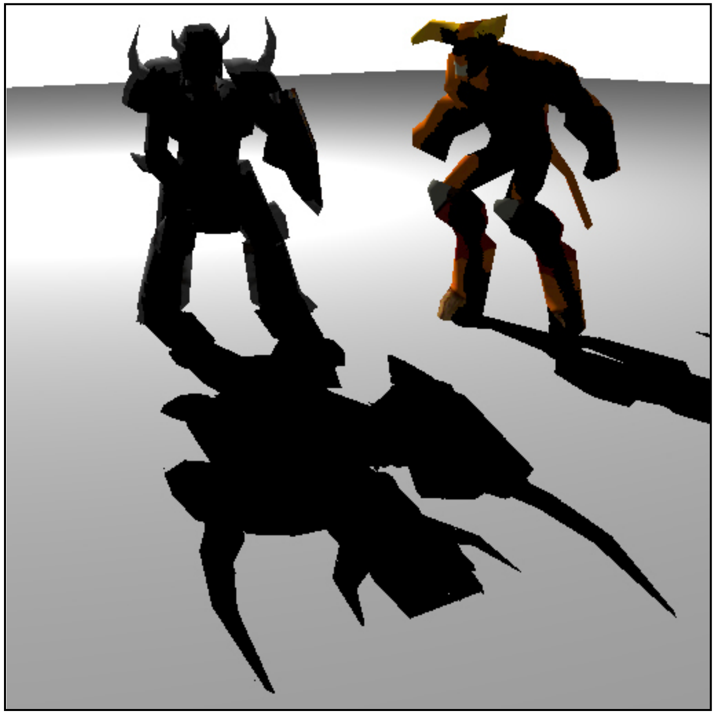
Illumination De-Multiplexing

Better signal to noise ratio.

Shadows

Attached and Cast Shadows





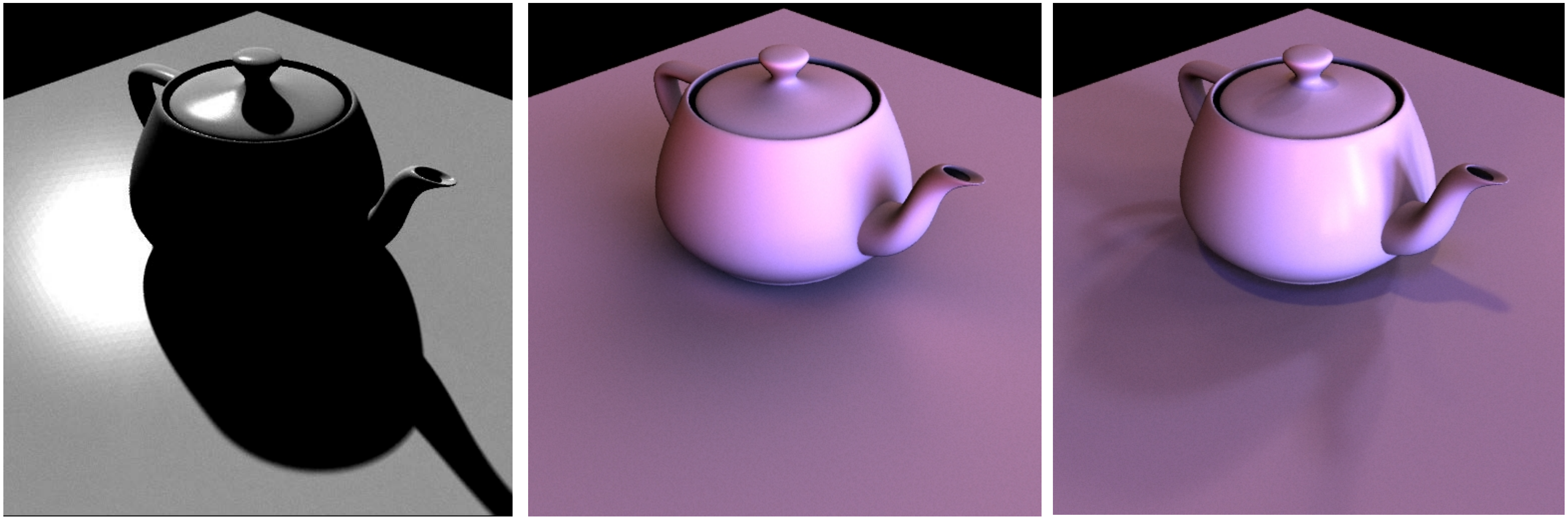
Sen, Cammarano, Hanrahan, 2003

Sloan, Kautz, Snyder 2002

Very hard shadows

Very soft shadows

All-Frequency Lighting and Shadows



Teapot in Grace Cathedral

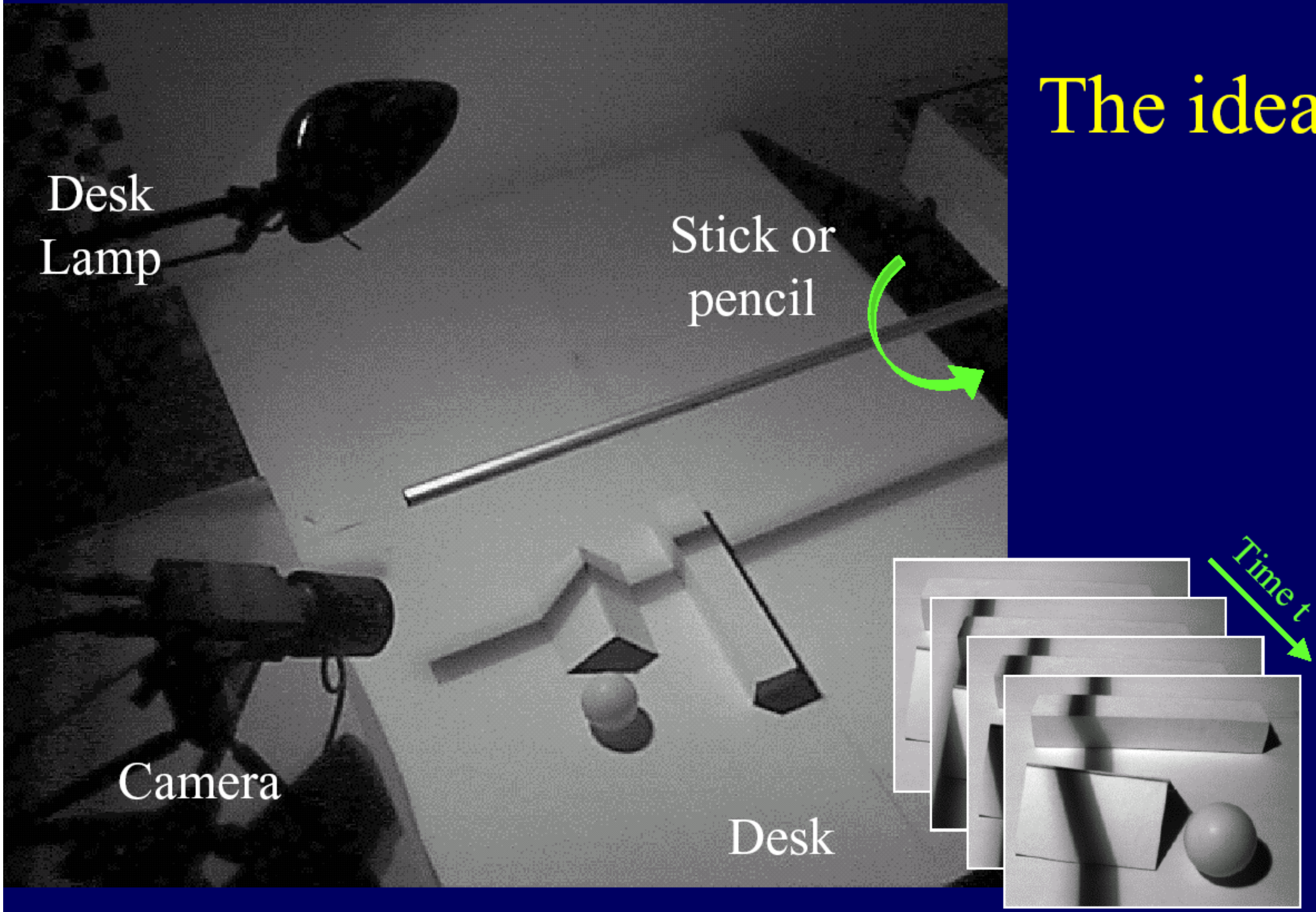
Sharper and Softer parts of Shadows

Point source model not good for rendering scenes.

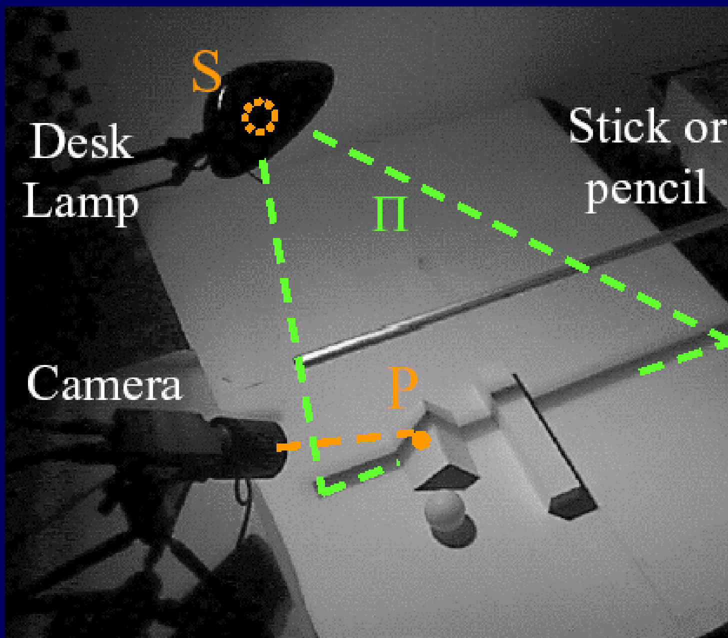
3D Acquisition from Shadows

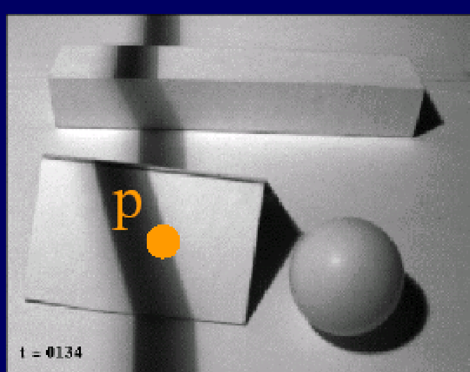
Bouguet-Perona, ICCV 98

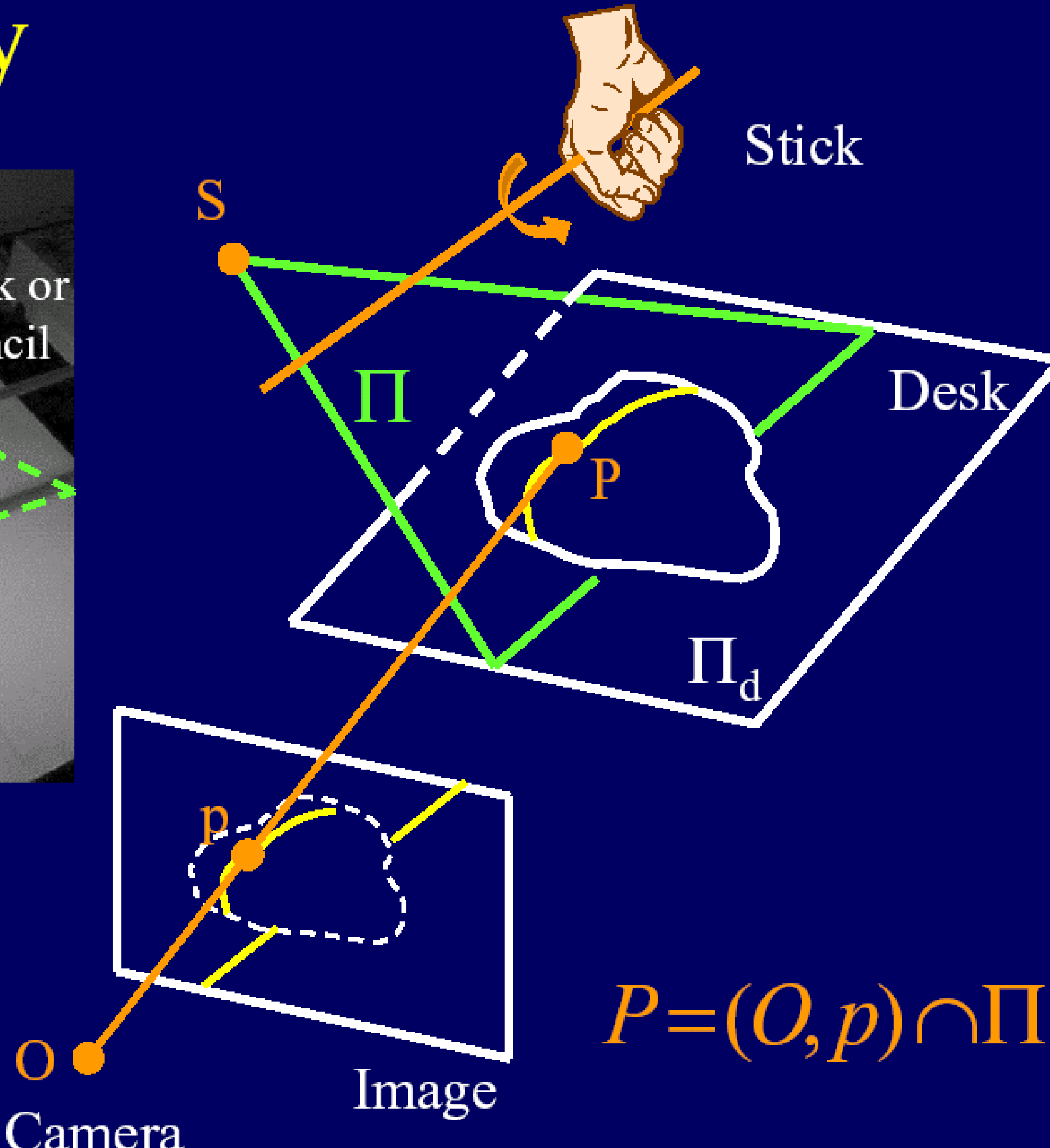
The idea



The geometry

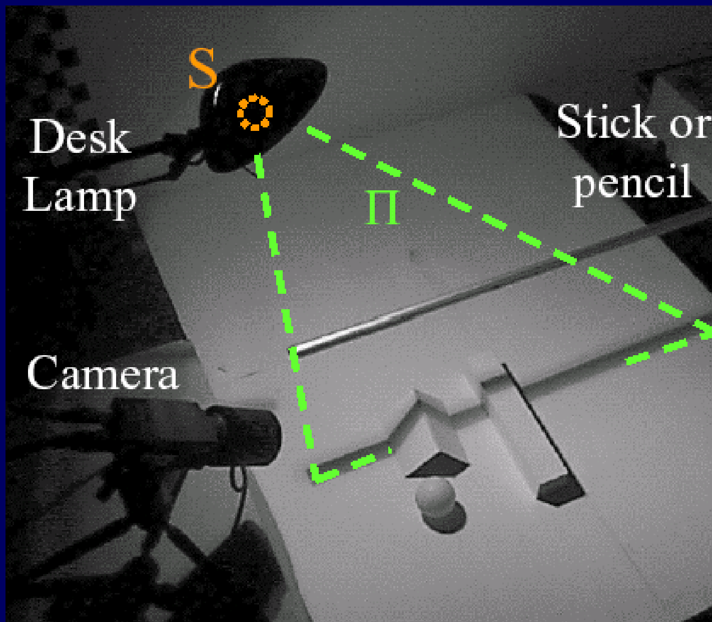


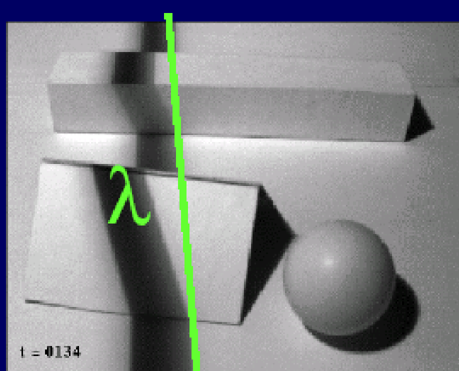


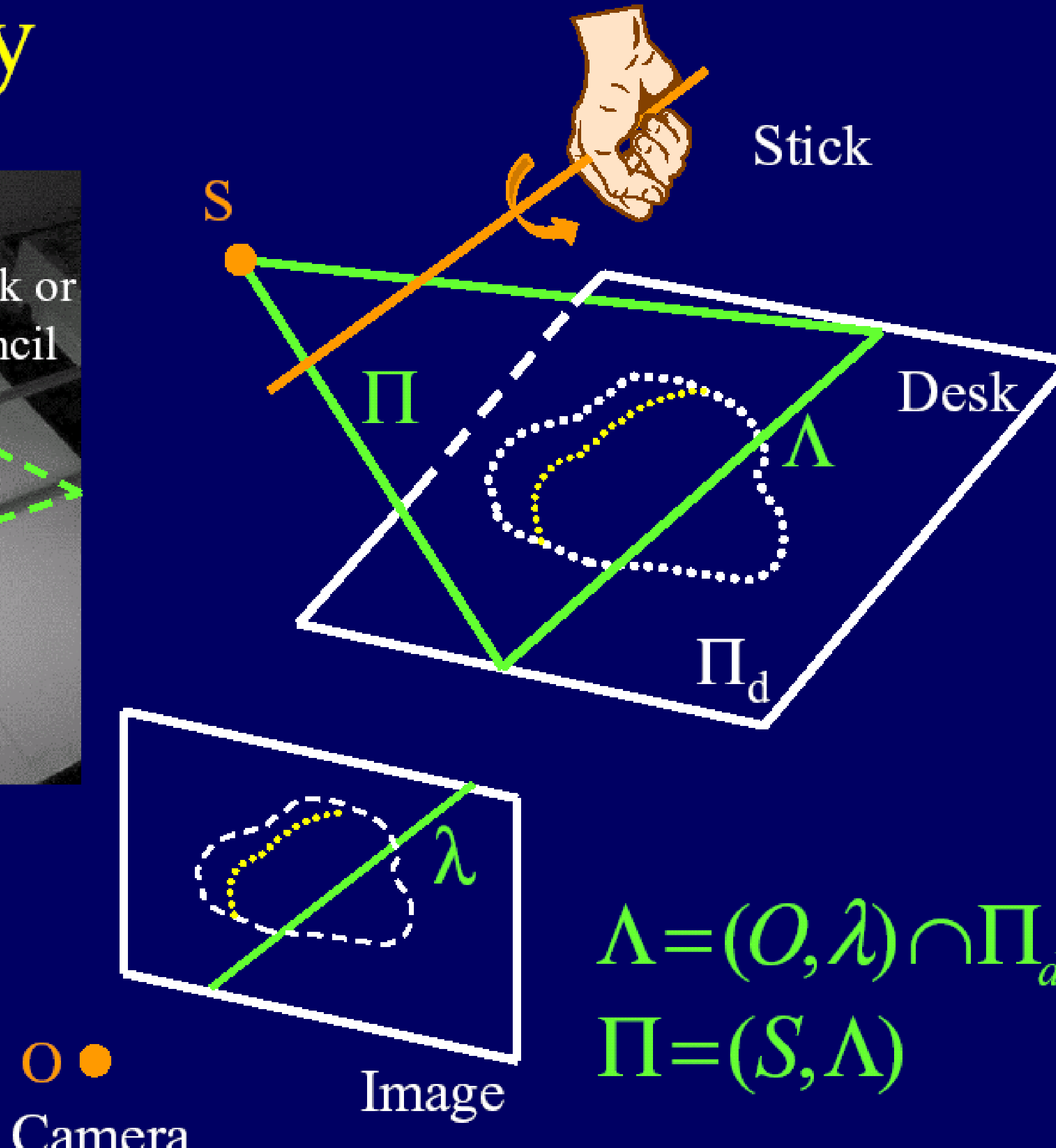


$$P = (O, p) \cap \Pi$$

The geometry



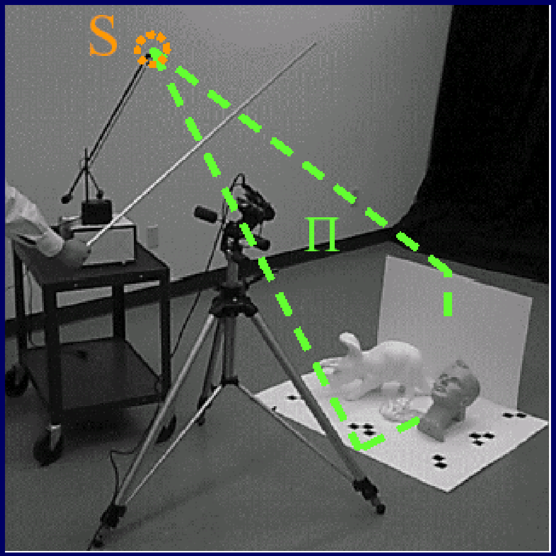


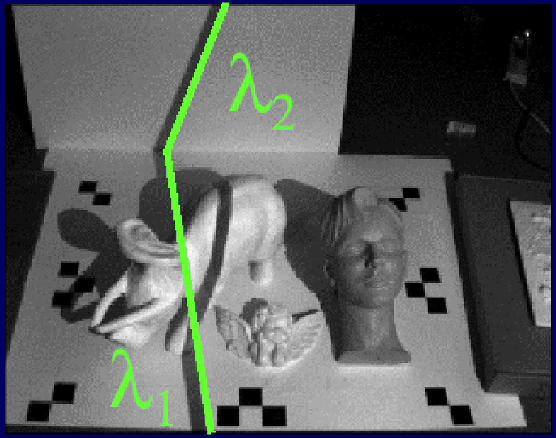


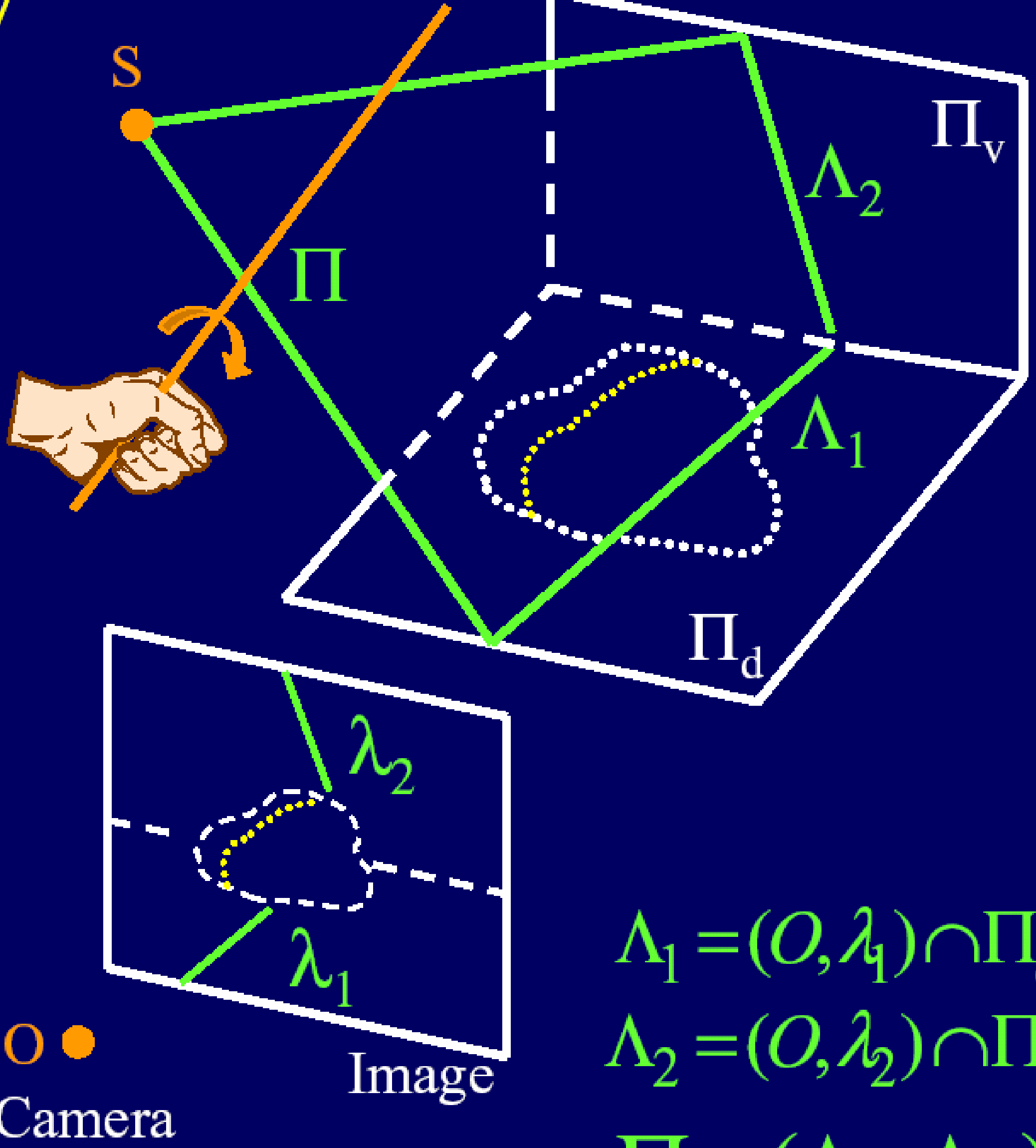
$$\Lambda = (O, \lambda) \cap \Pi_d$$

$$\Pi = (S, \Lambda)$$

The geometry





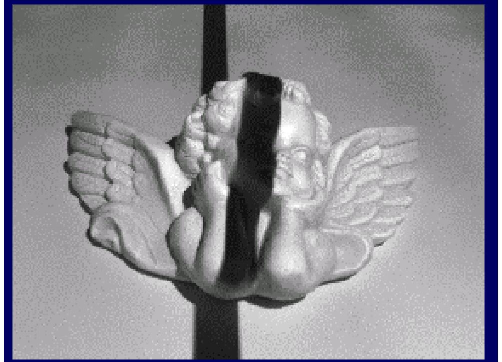


$$\Lambda_1 = (O, \lambda_1) \cap \Pi_d$$

$$\Lambda_2 = (O, \lambda_2) \cap \Pi_v$$

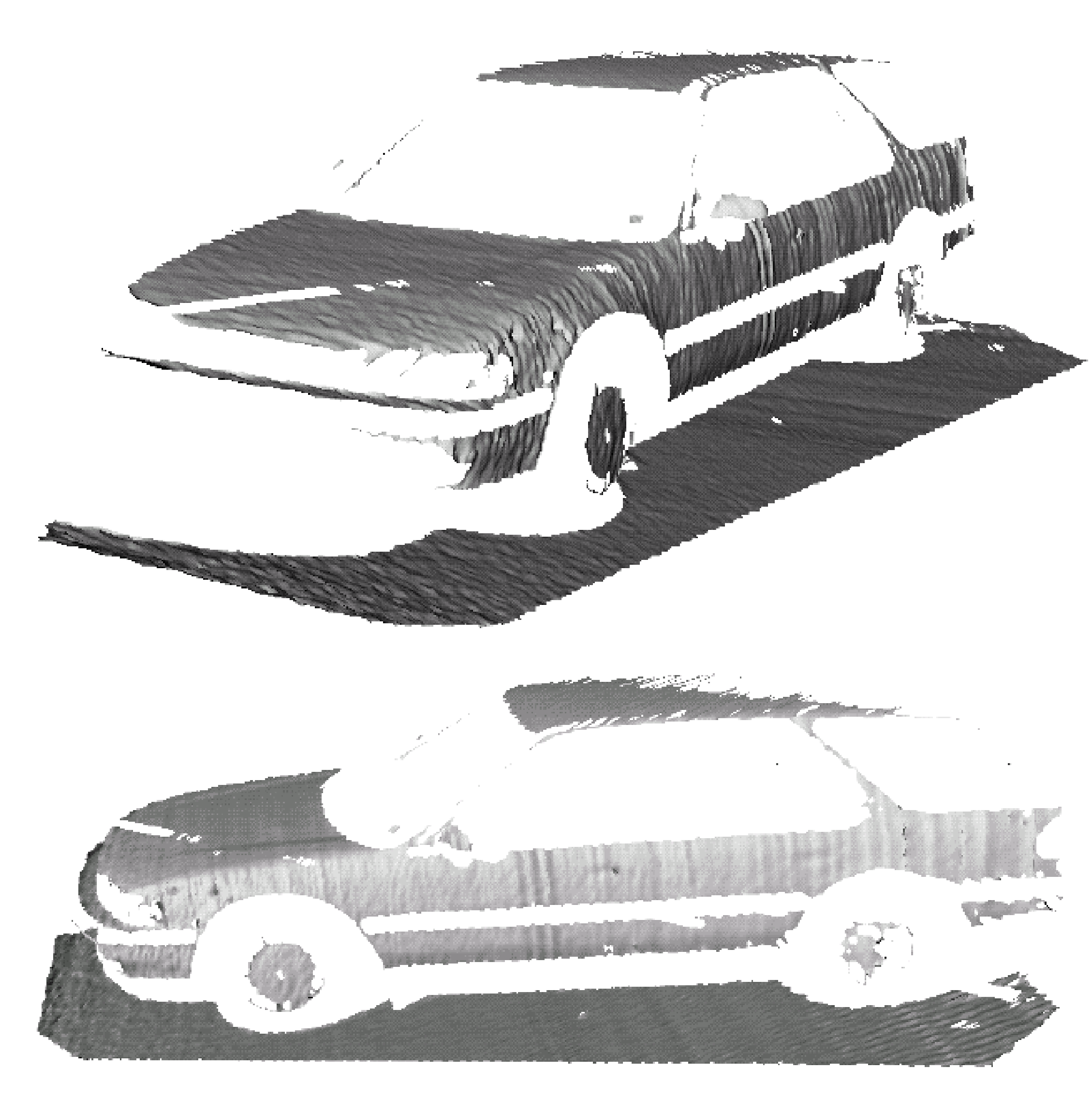
$$\Pi = (\Lambda_1, \Lambda_2)$$

Angel experiment



Accuracy: 0.1mm over 10cm → ~ 0.1% error

Scanning with the sun



Accuracy: 1cm over 2m

→ ~ 0.5% error