Introducción a la Fotografia 3D

UBA/FCEN Marzo 27 – Abril 12 2013

Clase 4 : Viernes Abril 5

Gabriel Taubin

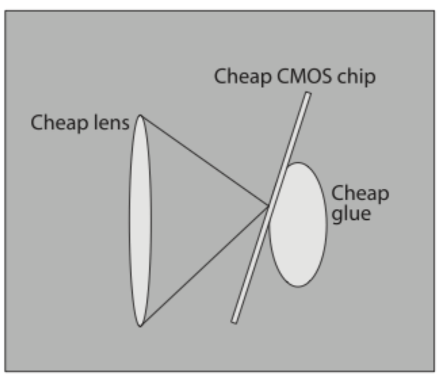
Brown University

BROWN

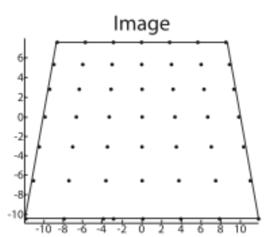
Course Schedule

- Introduction
- The Mathematics of 3D Triangulation
- 3D Scanning with Swept-Planes
- ***Camera and Swept-Plane Light Source Calibration***
- Reconstruction and Visualization using Point Clouds

Modeling Lens Distortion



Cheap camera



Without lens distortion distortion

$$\begin{bmatrix} x_p \\ y_p \end{bmatrix} = \begin{bmatrix} f_x X^W / Z^W + c_x \\ f_y X^W / Z^W + c_y \end{bmatrix}$$

G. Bradski and A. Kaehler. *Learning OpenCV*. O'Reilly Media, 2008

Modeling Lens Distortion

Radial distortion

$$x_{\text{corrected}} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

$$y_{\text{corrected}} = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

G. Bradski and A. Kaehler. *Learning OpenCV*. O'Reilly Media, 2008

Modeling Lens Distortion

Tangencial distortion

$$x_{\text{corrected}} = x + [2p_1 y + p_2(r^2 + 2x^2)]$$

$$y_{\text{corrected}} = y + [p_1(r^2 + 2y^2) + 2p_2 x]$$

G. Bradski and A. Kaehler. *Learning OpenCV*. O'Reilly Media, 2008

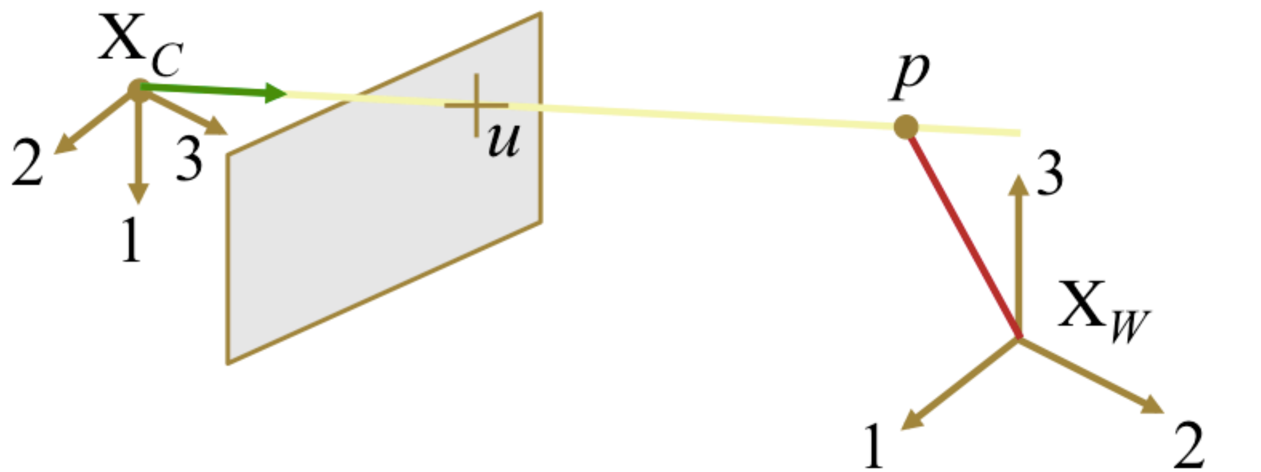
Modeling Lens Distortion

$$\begin{bmatrix} x_p \\ y_p \end{bmatrix} = (1 + k_1 r^2 + k_2 r^4 + k_3 r^6) \begin{bmatrix} x_d \\ y_d \end{bmatrix} + \begin{bmatrix} 2p_1 x_d y_d + p_2 (r^2 + 2x_d^2) \\ p_1 (r^2 + 2y_d^2) + 2p_2 x_d y_d \end{bmatrix}$$

G. Bradski and A. Kaehler. *Learning OpenCV*. O'Reilly Media, 2008

Intrinsic Camera Calibration

camera coordinate system | world coordinate system



$$\lambda u = K(R p_W + T)$$

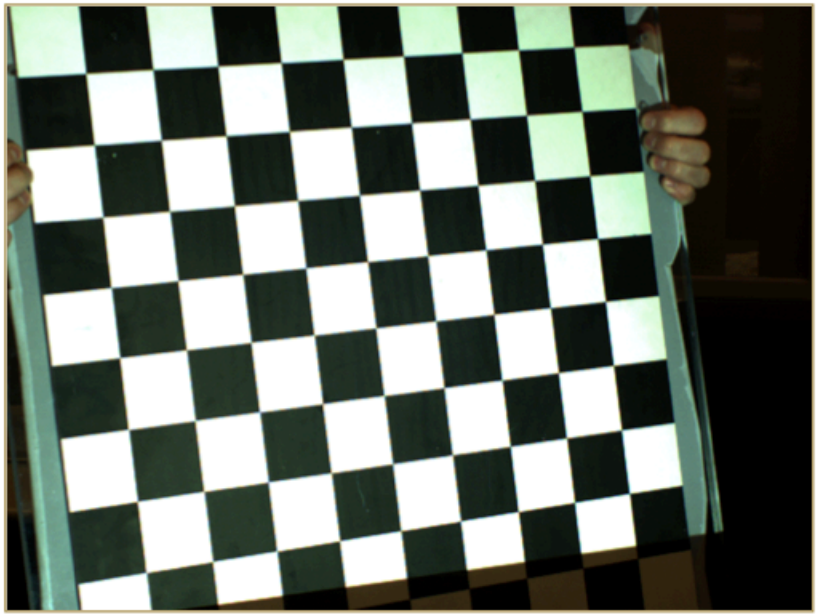
intrinsic parameters

$$X_C = R X_W + T$$

extrinsic parameters

- How to estimate intrinsic parameters and distortion model?
  (unknowns: focal length, skew, scale, principal point, and distortion coeffs.)

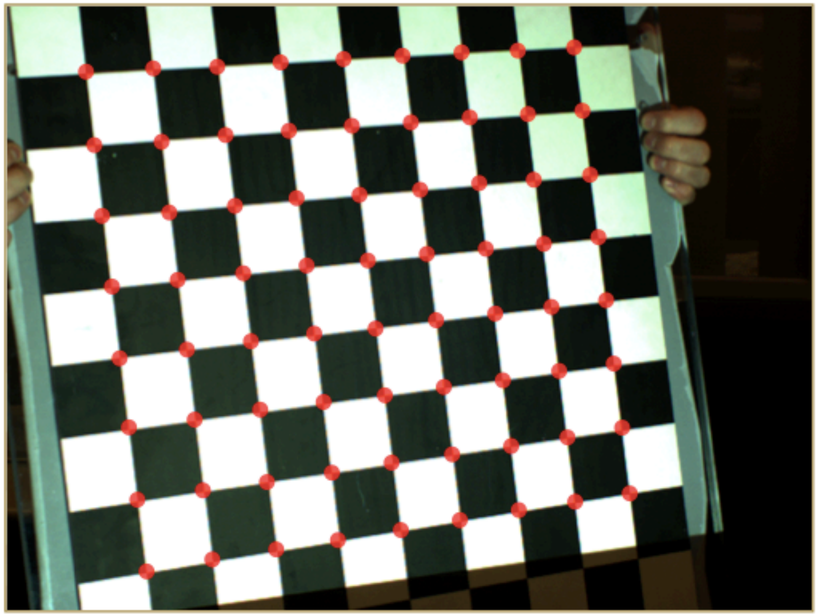
Intrinsic Camera Calibration



Camera Calibration Input

- How to estimate intrinsic parameters and distortion model?
  (unknowns: focal length, skew, scale, principal point, and distortion coeffs.)
- Popular solution: Observe a known calibration object (Zhang [2000])

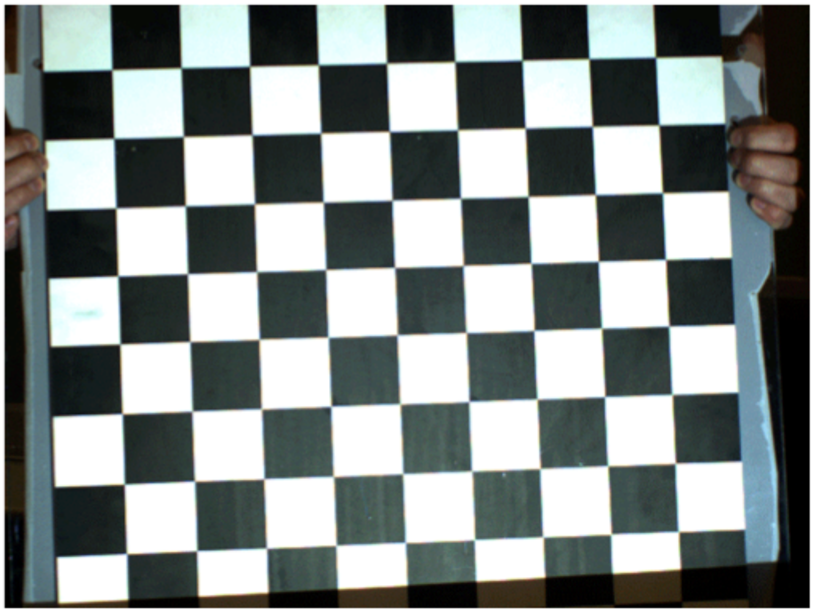
Intrinsic Camera Calibration



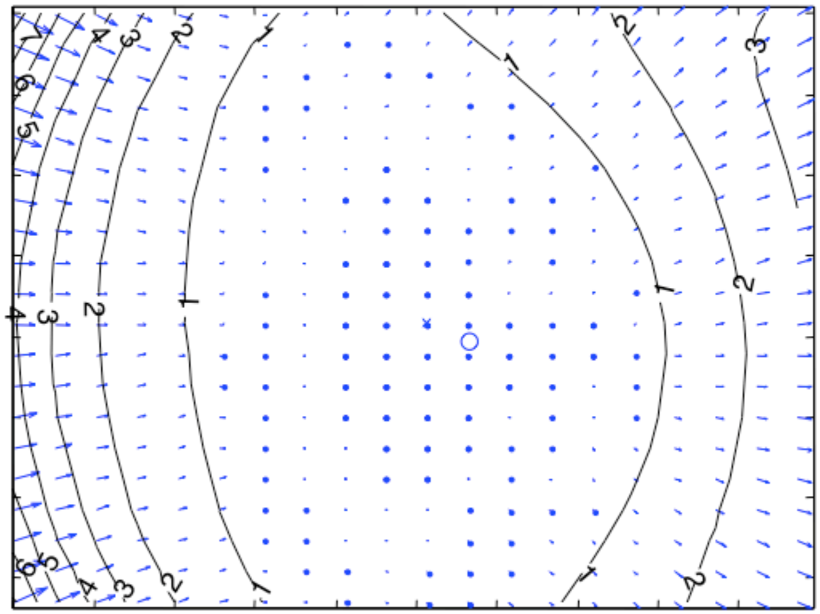
Camera Calibration Input

- How to estimate intrinsic parameters and distortion model?
(unknowns: focal length, skew, scale, principal point, and distortion coeffs.)
- Popular solution: Observe a known calibration object (Zhang [2000])
- Each 2D chessboard corner yields two constraints on the 6-11 unknowns

Intrinsic Camera Calibration



Camera Calibration Input



Estimated Camera Lens Distortion Map

- How to estimate intrinsic parameters and distortion model?
  (unknowns: focal length, skew, scale, principal point, and distortion coeffs.)
- Popular solution: Observe a known calibration object (Zhang [2000])
- Each 2D chessboard corner yields two constraints on the 6-11 unknowns
- But, must also find 6 extrinsic parameters per image (rotation/translation)
- ➔ **Result: Two or more images of a chessboard are sufficient**

OpenCV

Learning OpenCV

Gary Bradski and Adrian Kaehler

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CHAPTER 11

Camera Models and Calibration

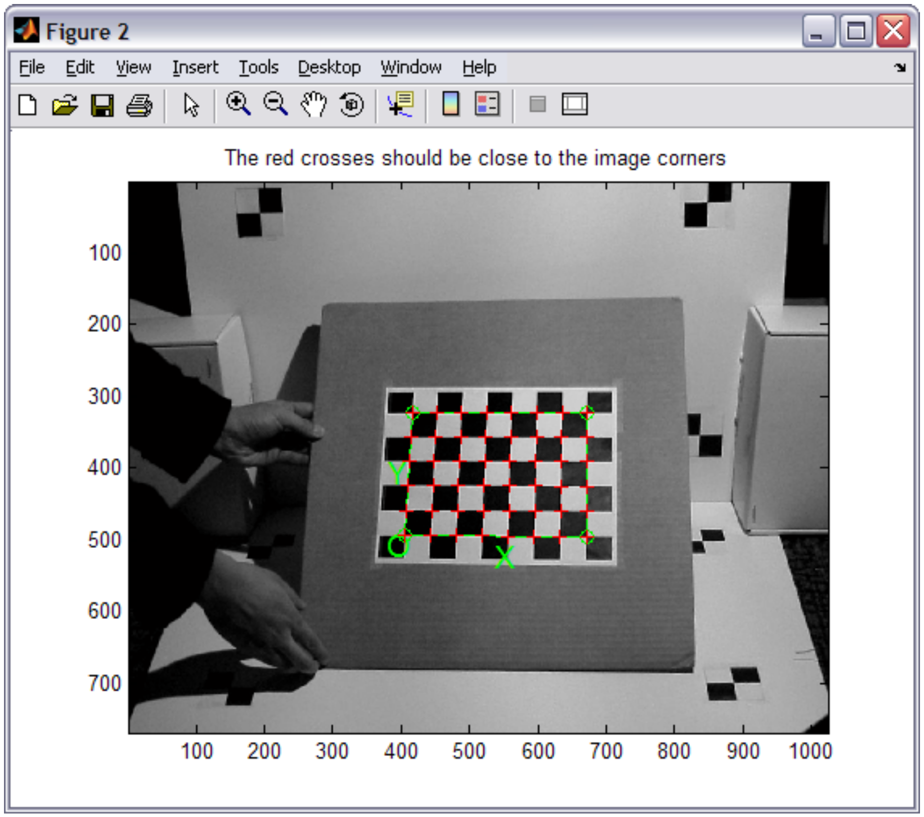
Vision begins with the detection of light from the world. That light begins as rays emanating from some source (e.g., a light bulb or the sun), which then travels through space until striking some object. When that light strikes the object, much of the light is absorbed, and what is not absorbed we perceive as the color of the light. Reflected light that makes its way to our eye (or our camera) is collected on our retina (or our imager). The geometry of this arrangement—particularly of the ray's travel from the object, through the lens in our eye or camera, and to the retina or imager—is of particular importance to practical computer vision.

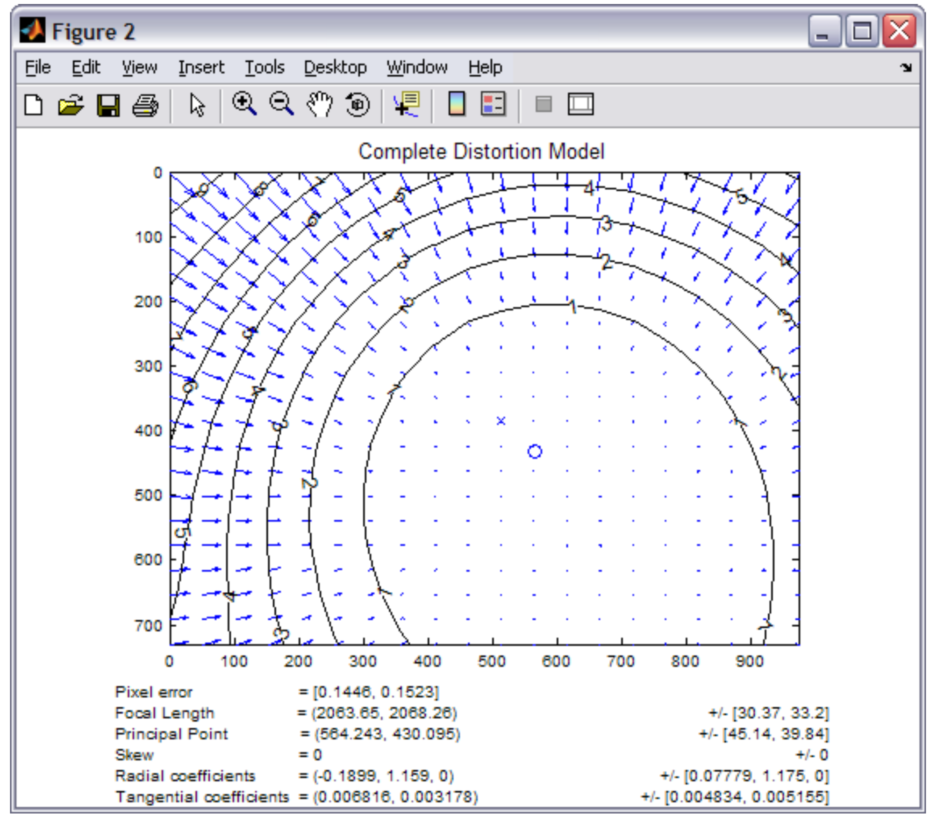
A simple but useful model of how this happens is the pinhole camera model.* A *pinhole* is an imaginary wall with a tiny hole in the center that blocks all rays except those passing through the tiny aperture in the center. In this chapter, we will start with a pinhole camera model to get a handle on the basic geometry of projecting rays. Unfortunately, a real pinhole is not a very good way to make images because it does not gather enough light for rapid exposure. This is why our eyes and cameras use lenses to gather more light than what would be available at a single point. The downside, however, is that gathering more light with a lens not only forces us to move beyond the simple geometry of the pinhole model but also introduces distortions from the lens itself.

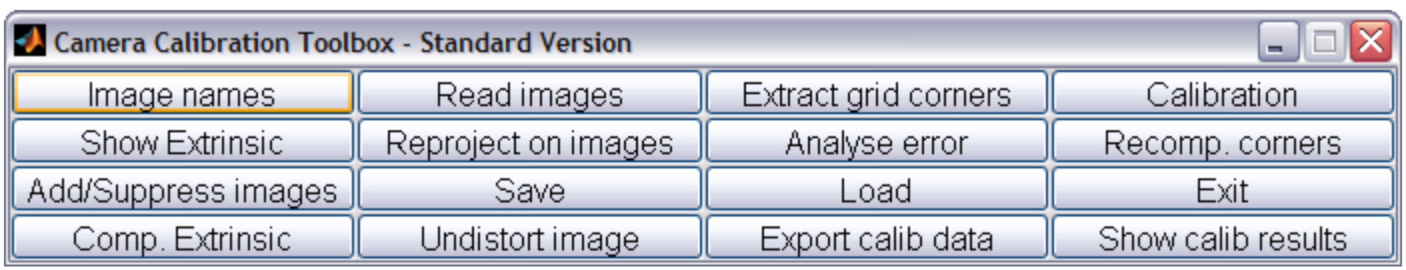
In this chapter we will learn how, using *camera calibration*, to correct (mathematically) for the main deviations from the simple pinhole model that the use of lenses imposes on us. Camera calibration is important also for relating camera measurements with measurements in the real, three-dimensional world. This is important because scenes are not only three-dimensional; they are also physical spaces with physical units. Hence, the relation between the camera's natural units (pixels) and the units of the

* Knowledge of lenses goes back at least to Roman times. The pinhole camera model goes back at least 987 years to al-Hytham [1021] and is the classic way of introducing the geometric aspects of vision. Mathematical and physical advances followed in the 1600s and 1700s with Descartes, Kepler, Galileo, Newton, Hooke, Euler, Fermat, and Snell (see O'Connor [O'Connor02]). Some key modern texts for geometric vision include those by Trucco [Trucco98], Jaehne (also sometimes spelled Jähne) [Jaehne95; Jaehne97], Hartley and Zisserman [Hartley06], Forsyth and Ponce [Forsyth03], Shapiro and Stockman [Shapiro02], and Xu and Zhang [Xu96].

Demo: Camera Calibration in Matlab

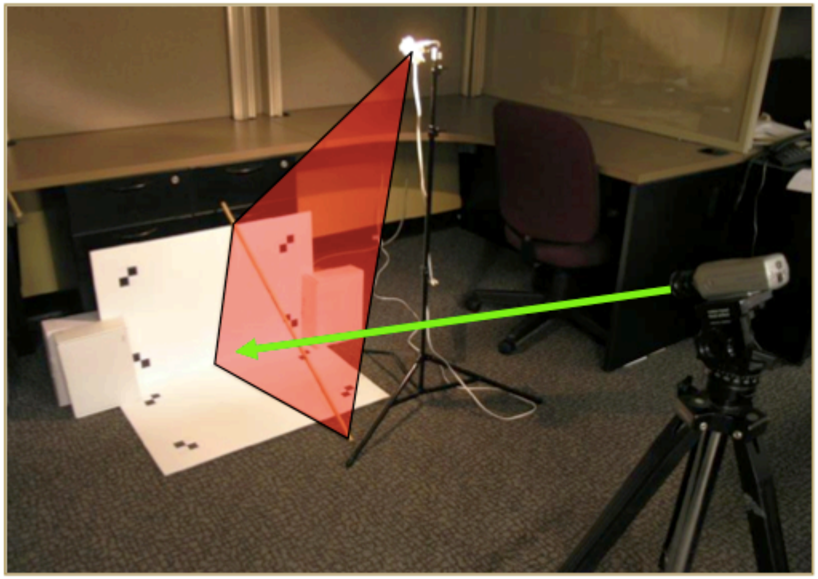


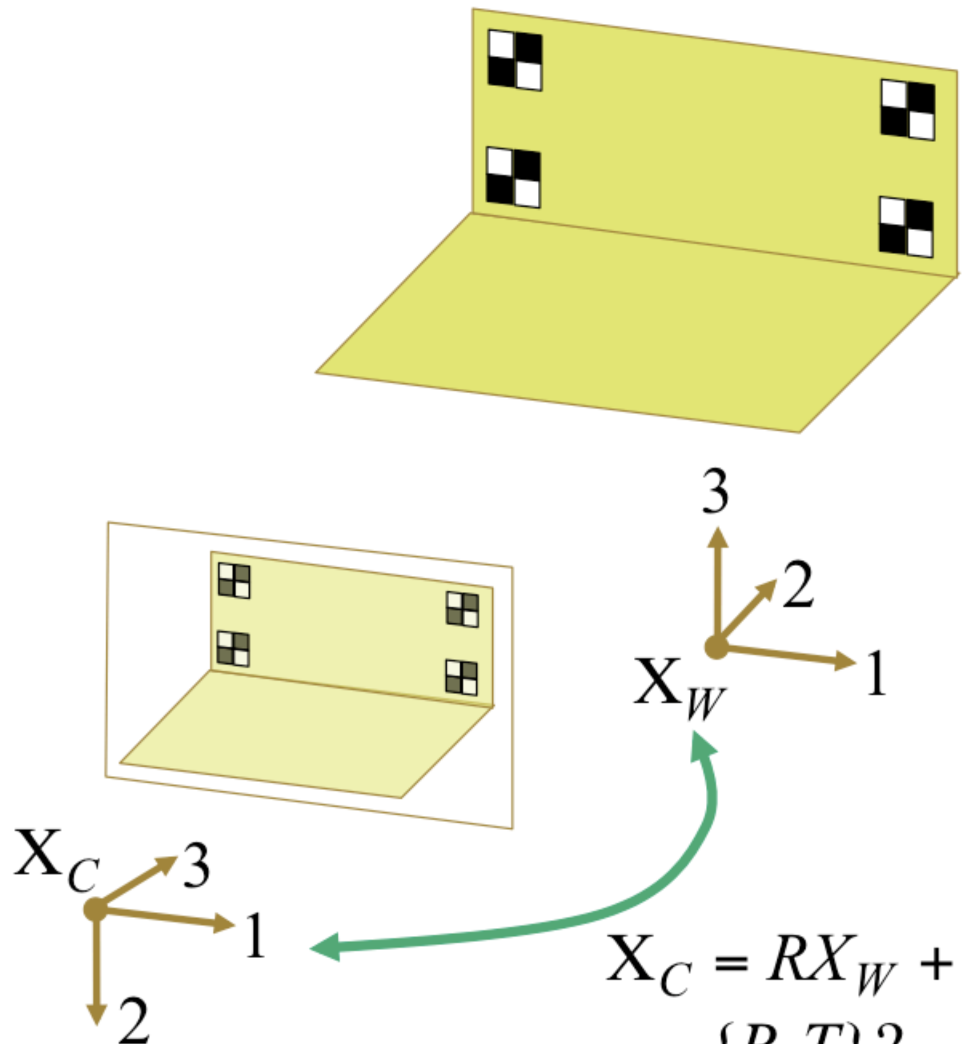




J.-Y. Bouguet. Camera Calibration Toolbox for Matlab. http://www.vision.caltech.edu/bouguetj/calib_doc/

Extrinsic Camera Calibration

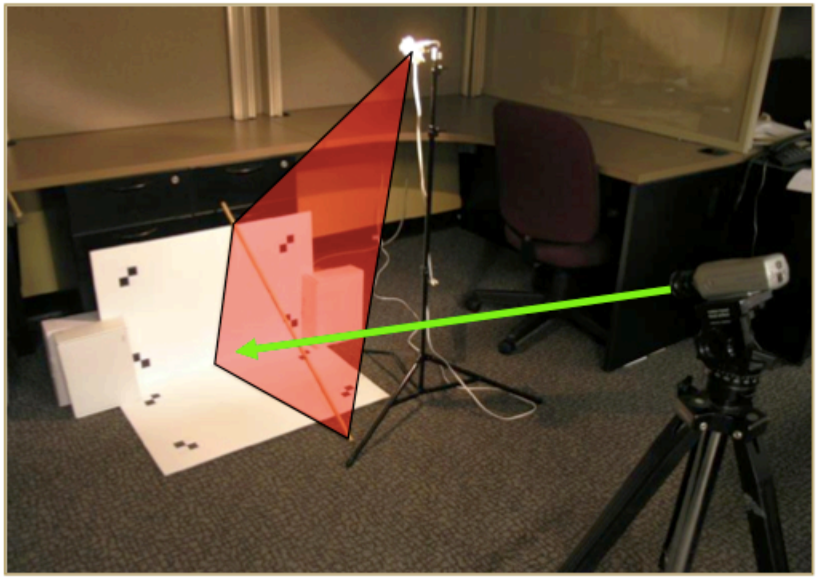


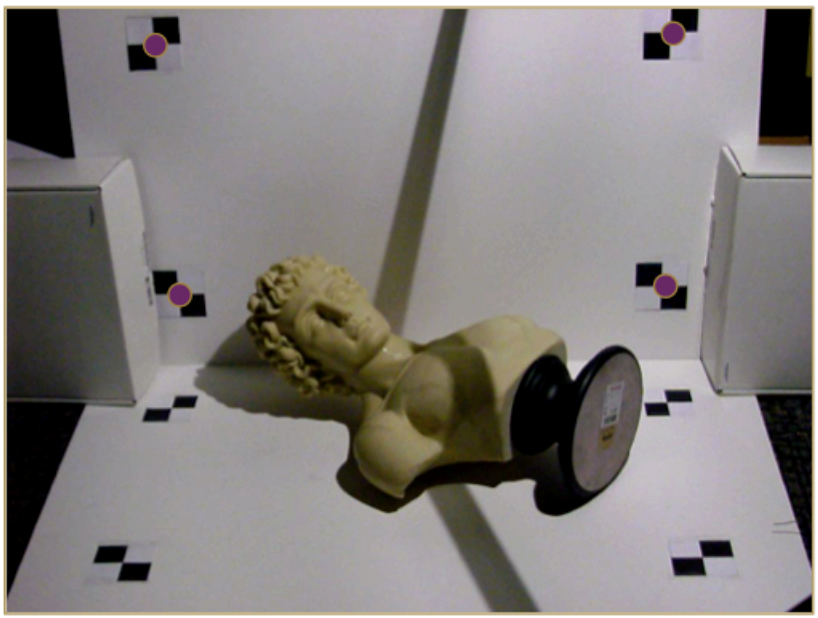


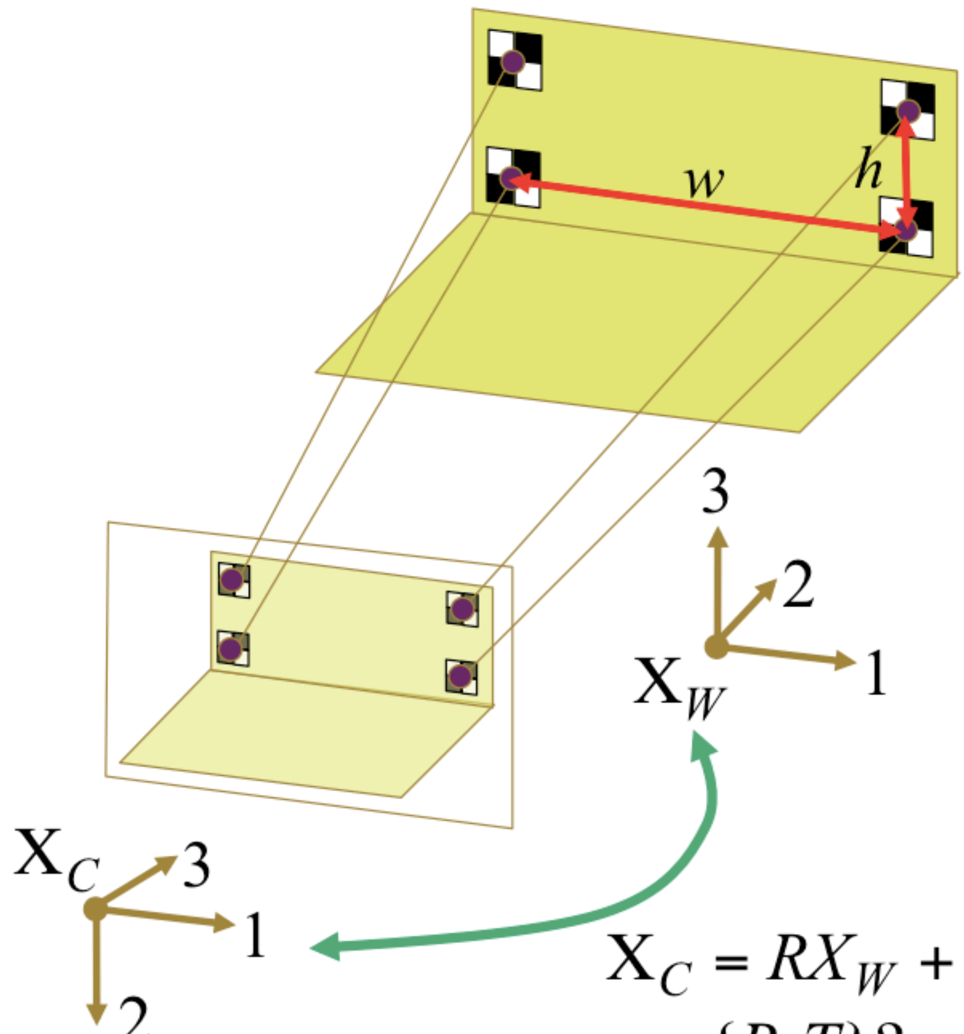
$$X_C = RX_W + T$$

$$\{R, T\}?$$

Extrinsic Camera Calibration



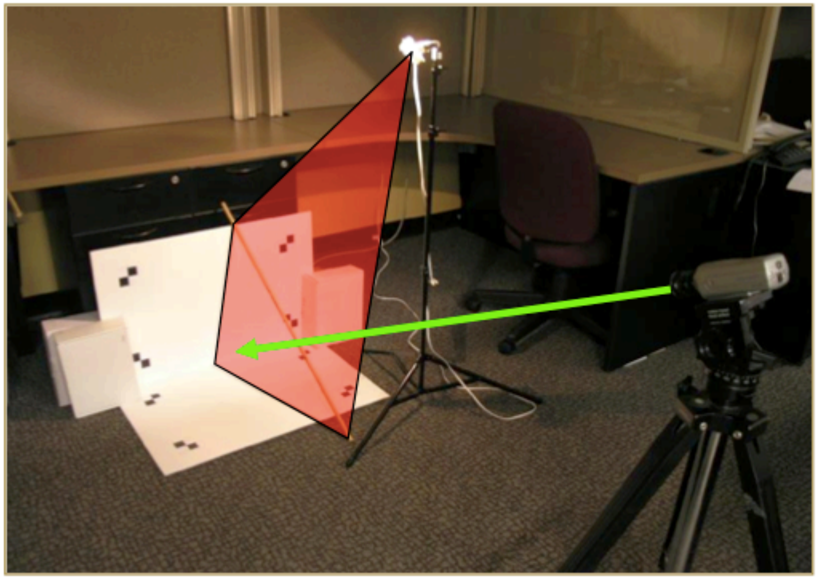


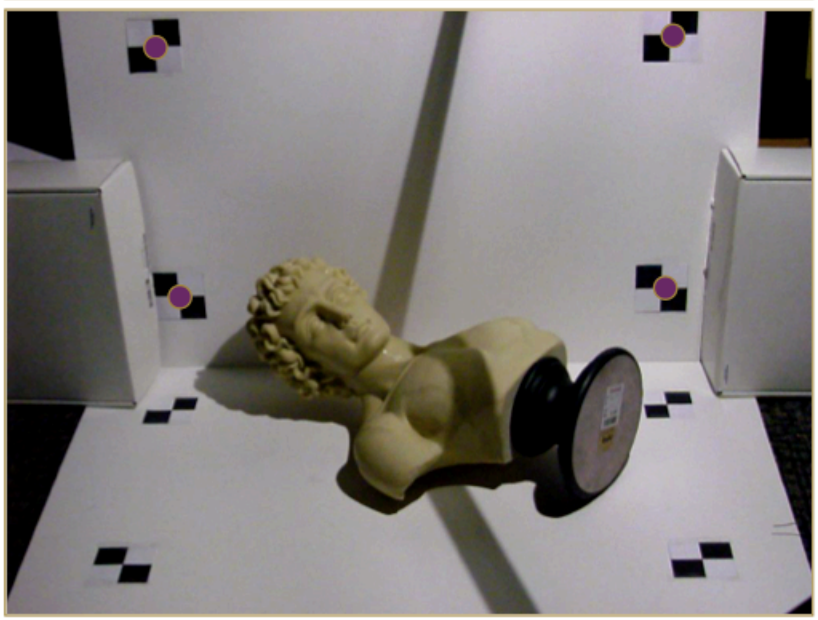


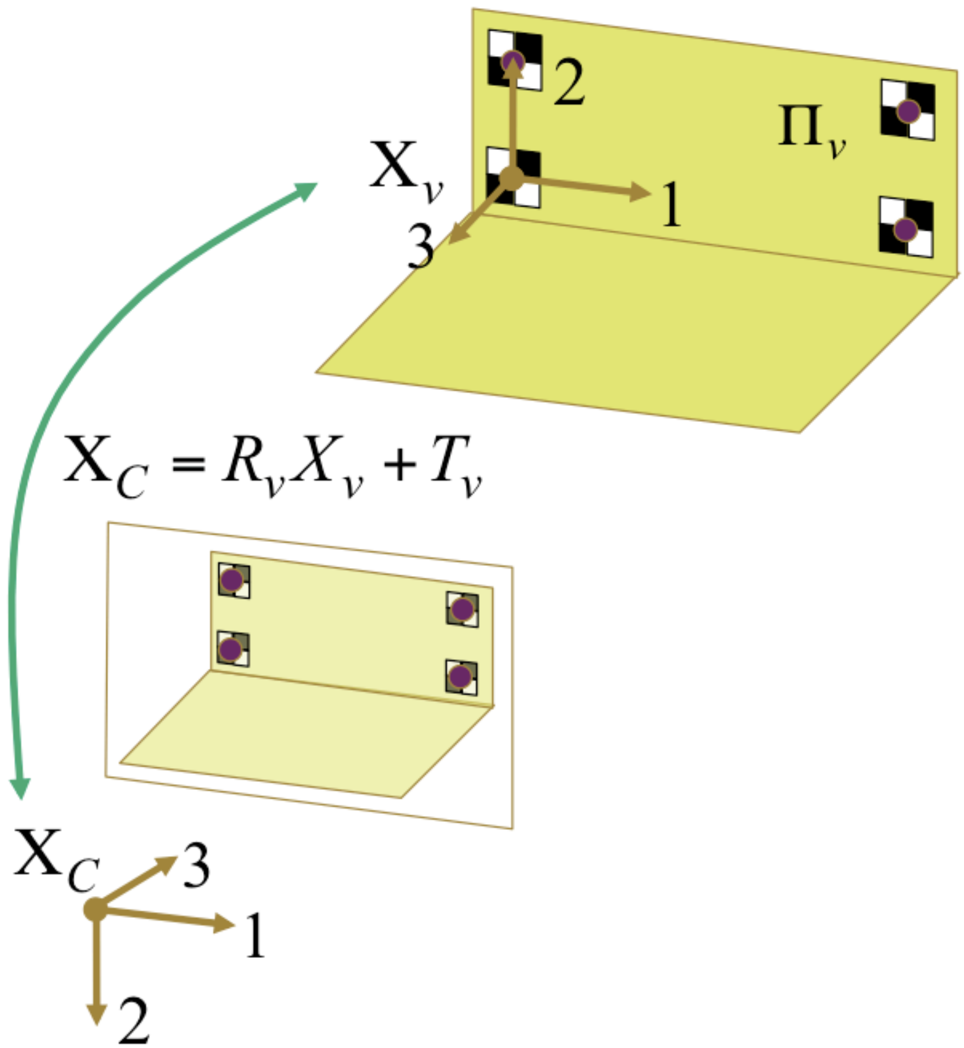
$$X_C = RX_W + T$$

$$\{R, T\}?$$

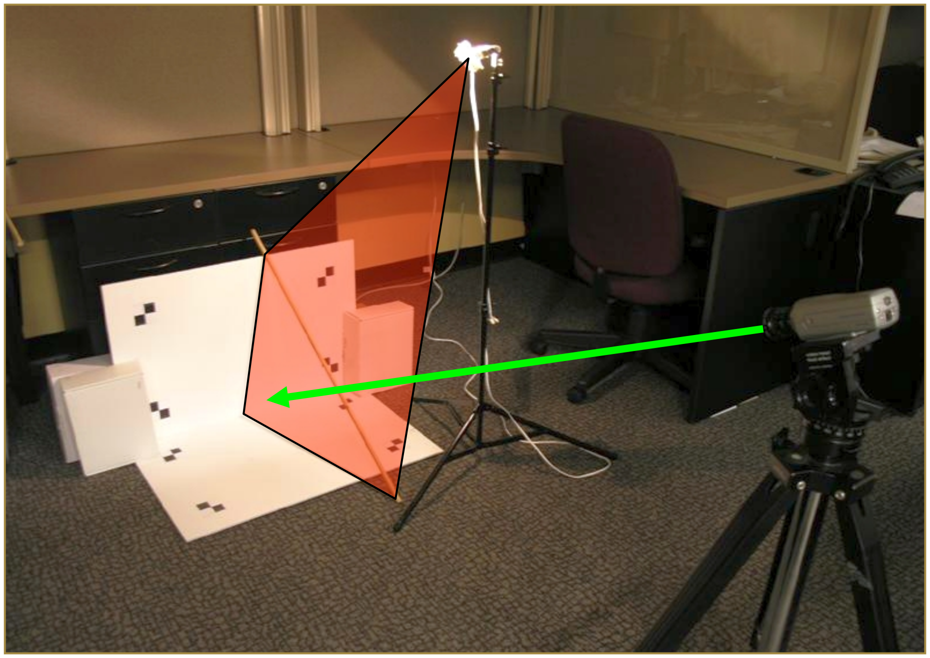
Extrinsic Camera Calibration

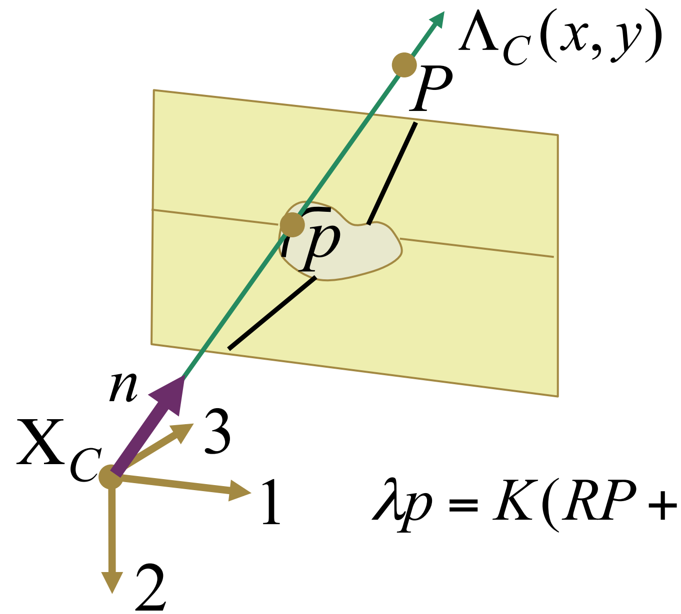






Demo: Mapping Pixels to Optical Rays



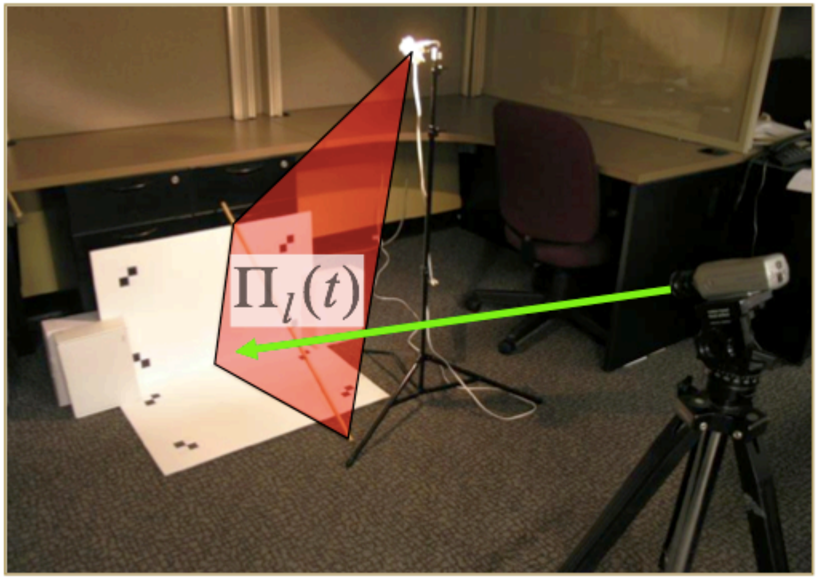


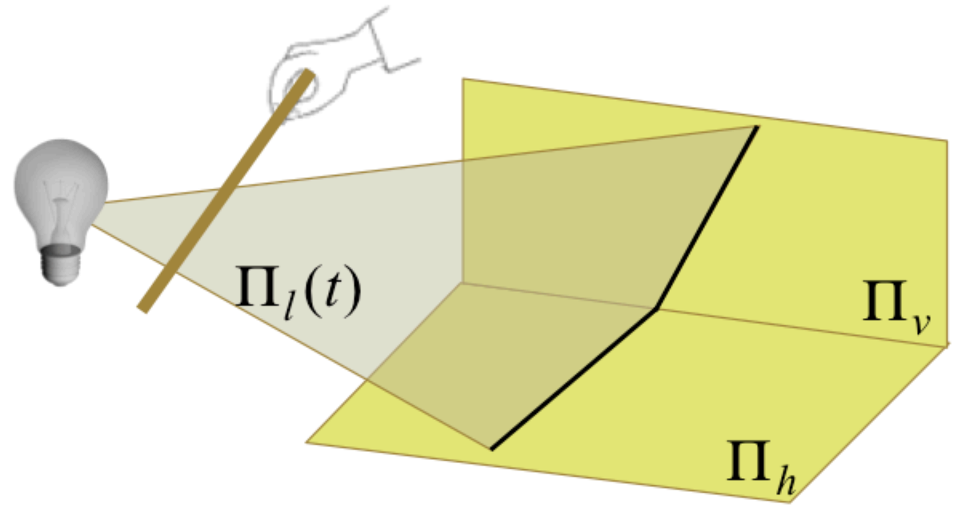
$$\lambda p = K(RP + T)$$

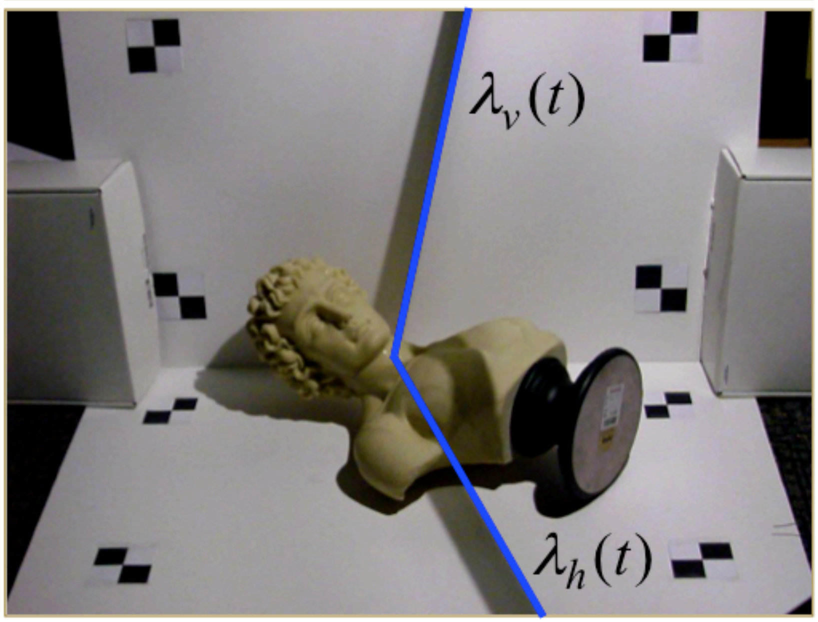
- How to map an image pixel to an optical ray?
- Solution: Invert the *calibrated* camera projection model
- But, also requires inversion of distortion model (which is non-linear)
- Mapping implemented in Camera Calibration Toolbox with **normalize.m**

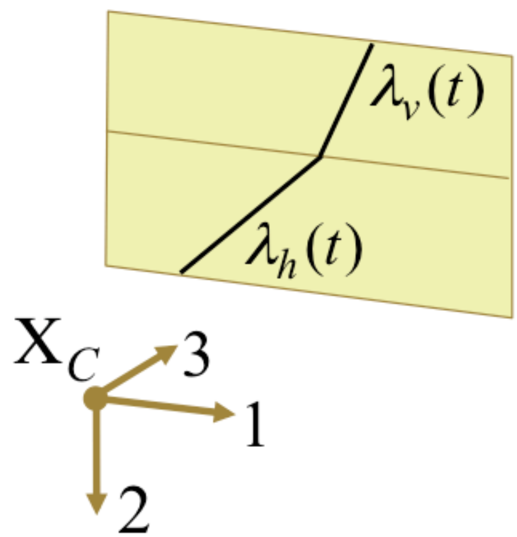
➔ **Result: After calibration, pixels can be converted to optical rays**

Shadow Plane Calibration

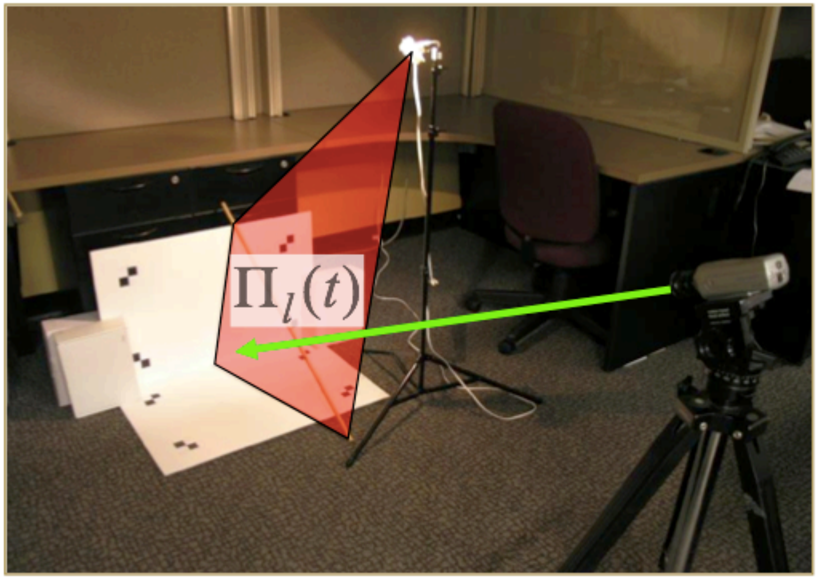


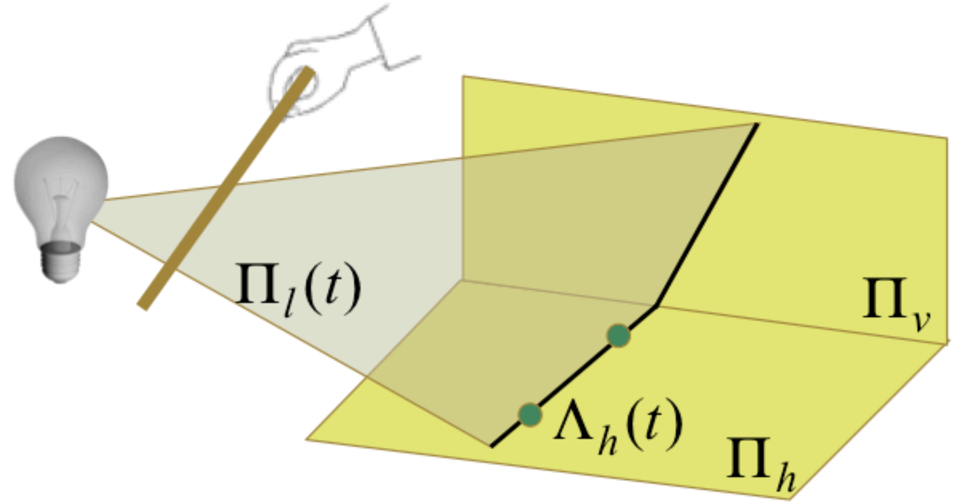


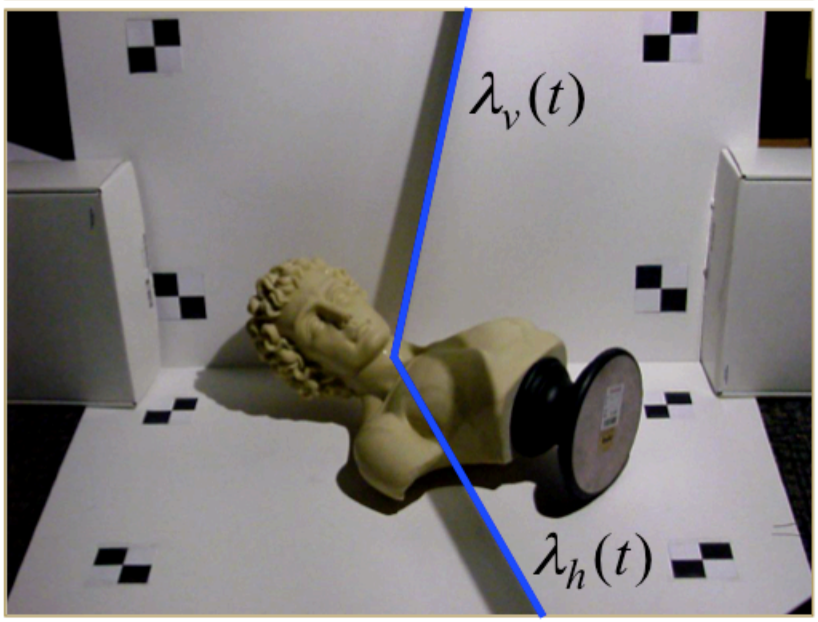


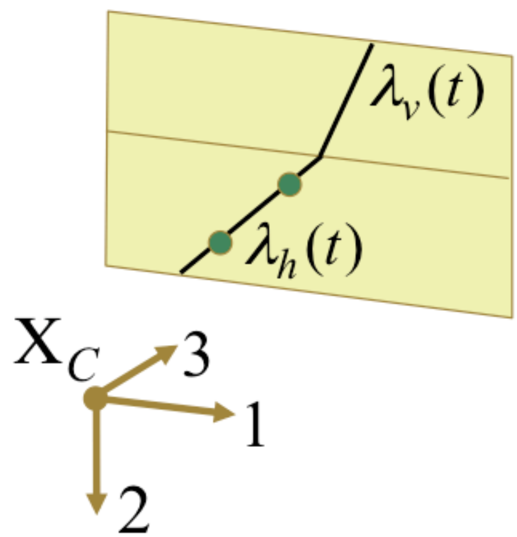


Shadow Plane Calibration

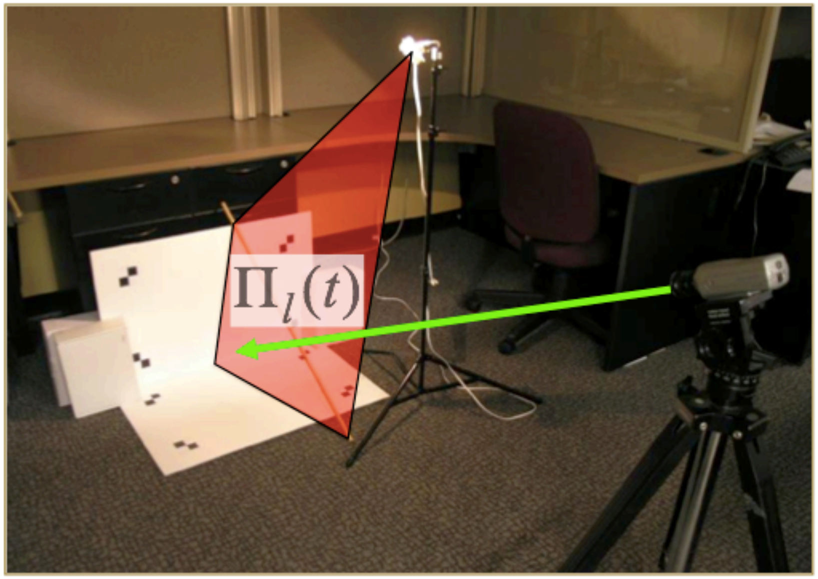


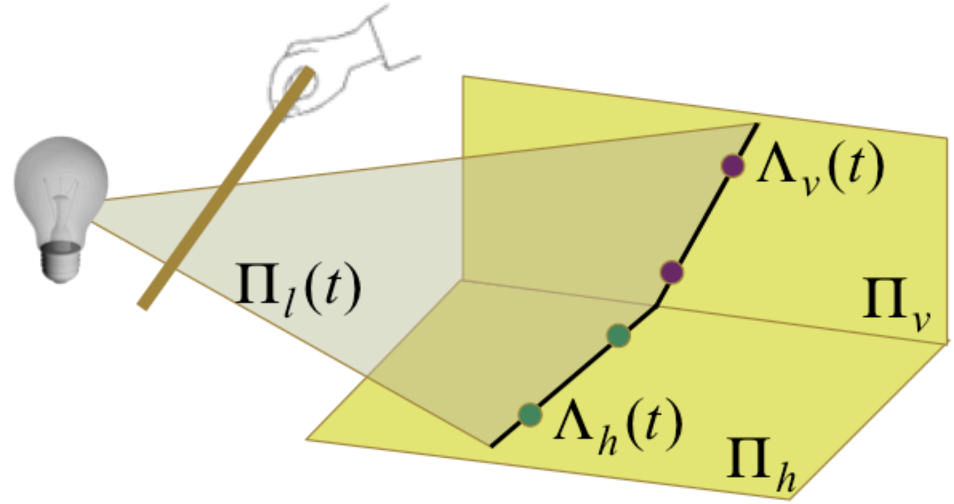


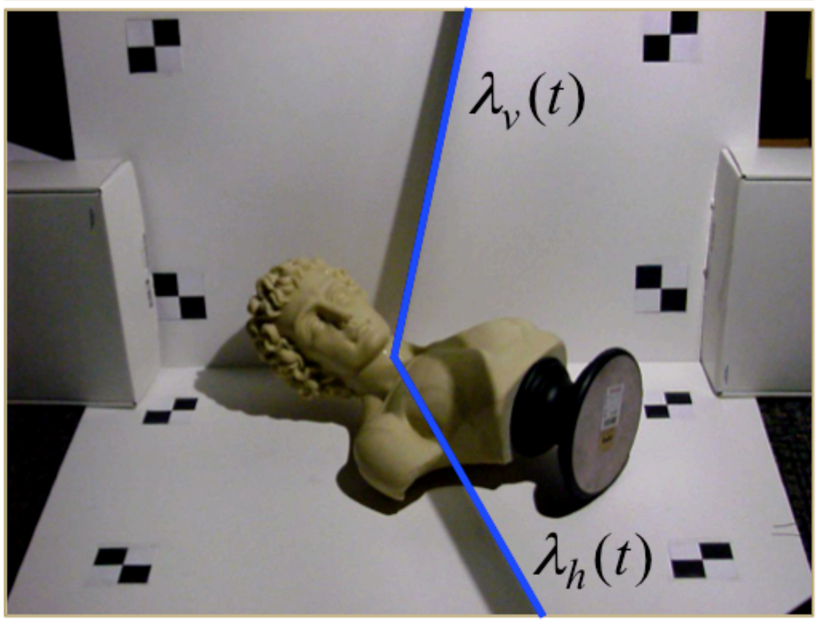


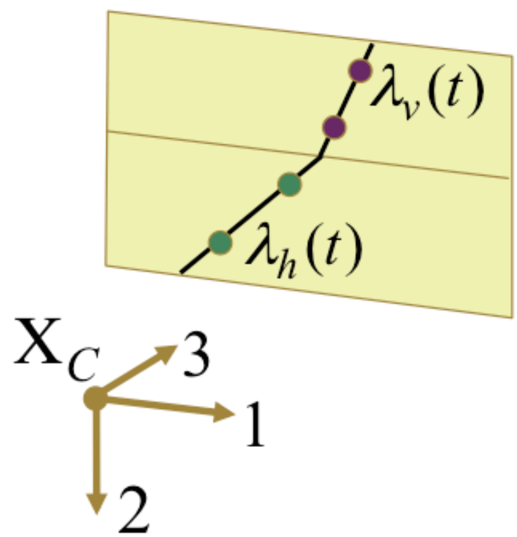


Shadow Plane Calibration

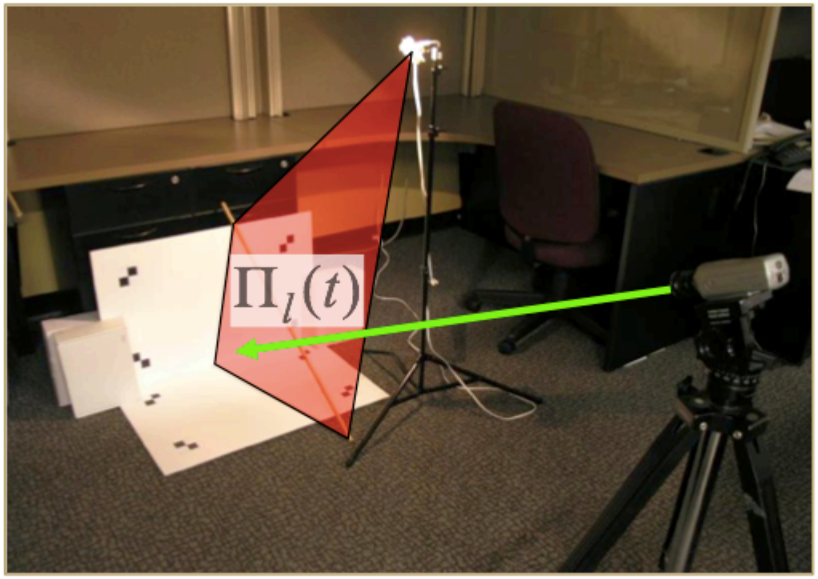


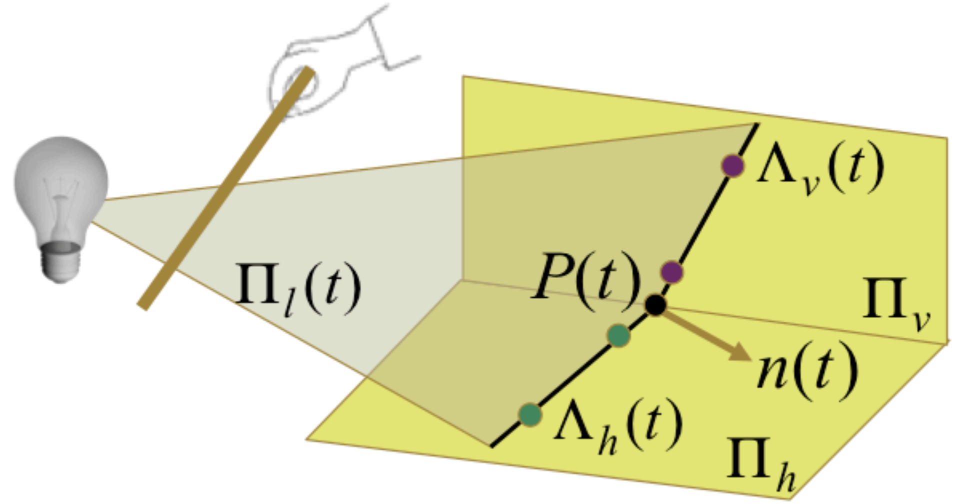


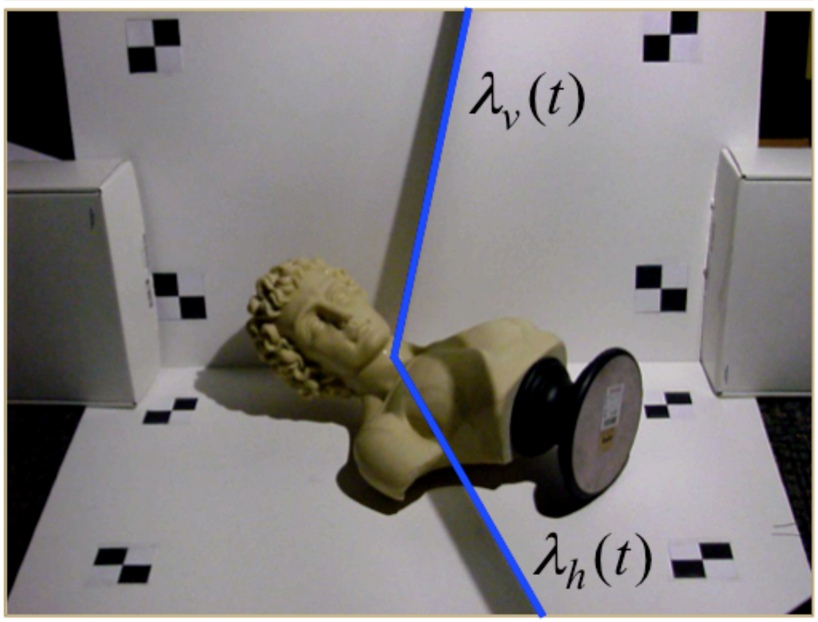


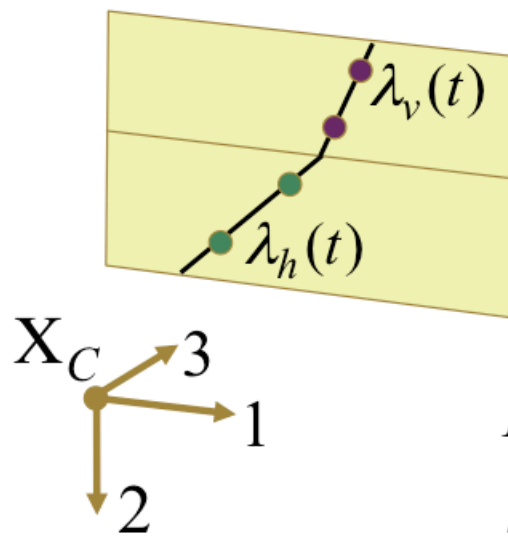


Shadow Plane Calibration





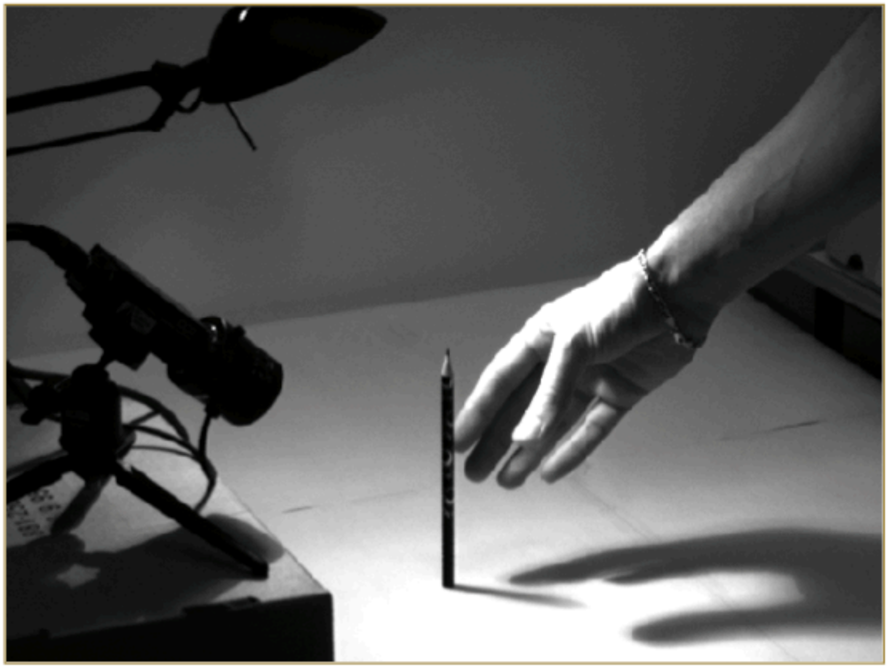


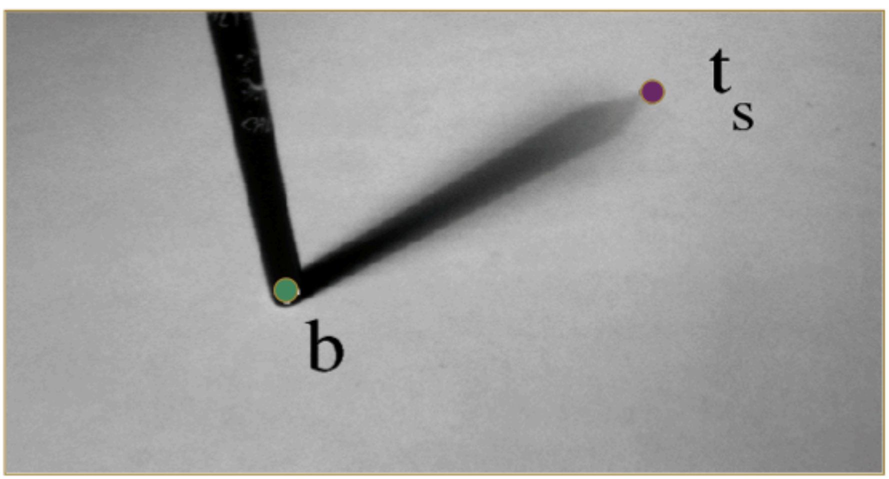


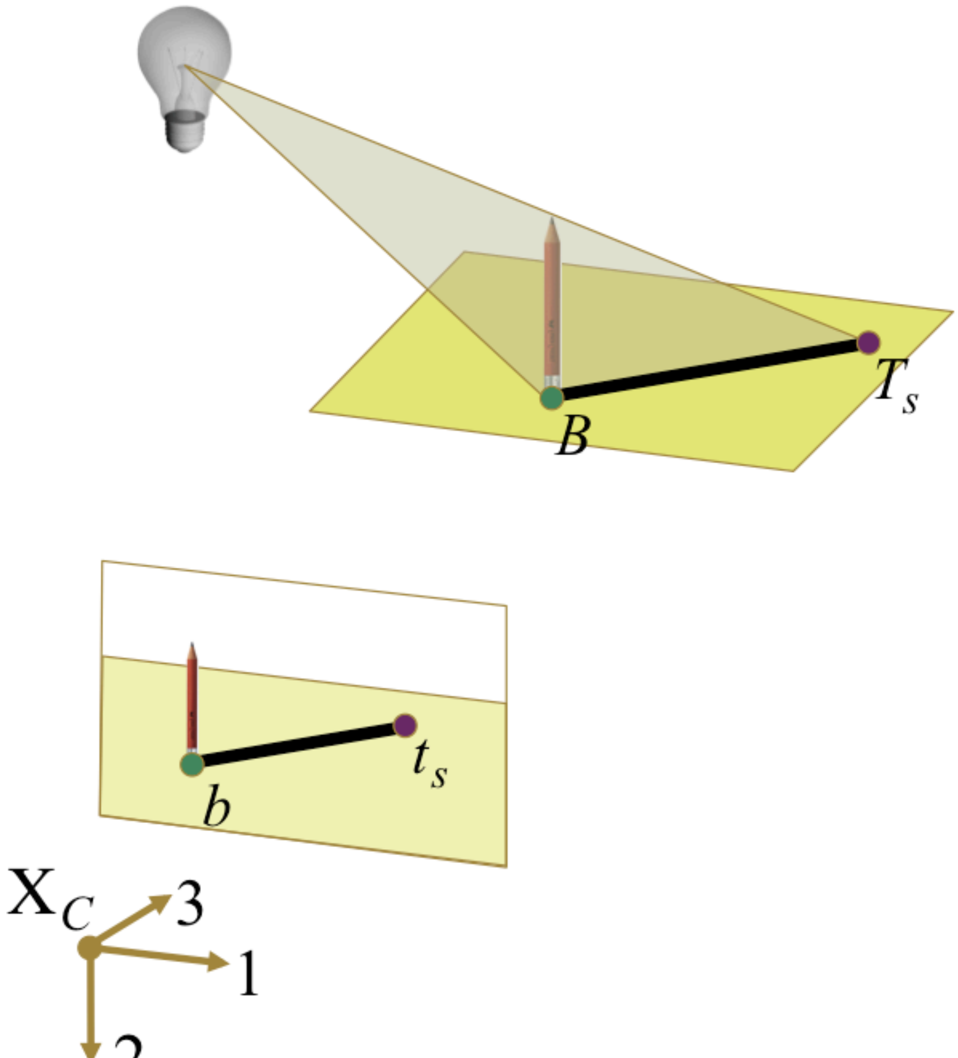
$$P(t) = \Lambda_h(t) \cap \Lambda_v(t)$$

$$n(t) = \Lambda_h(t) \otimes \Lambda_v(t)$$

Alternatives for Shadow Plane Calibration

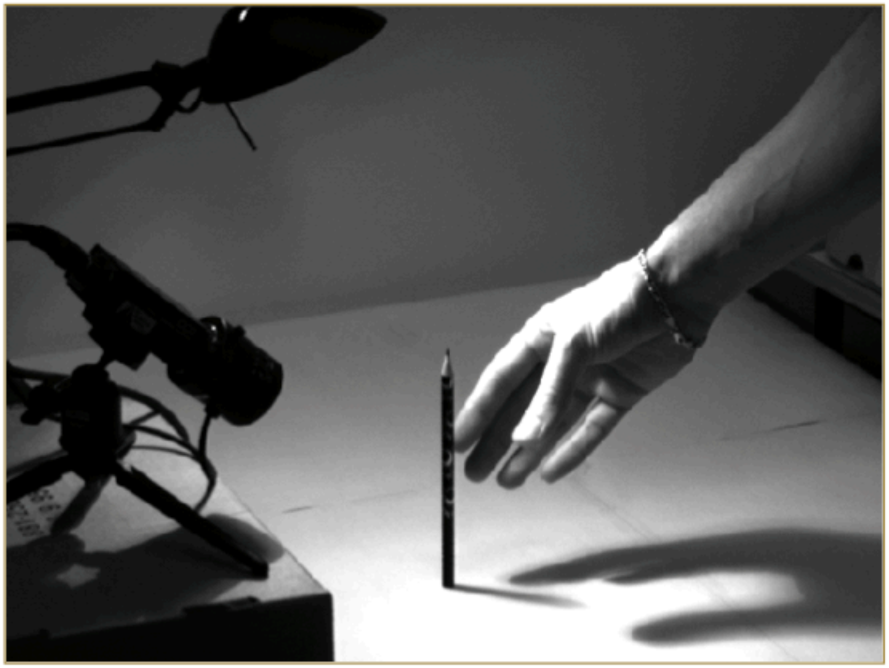


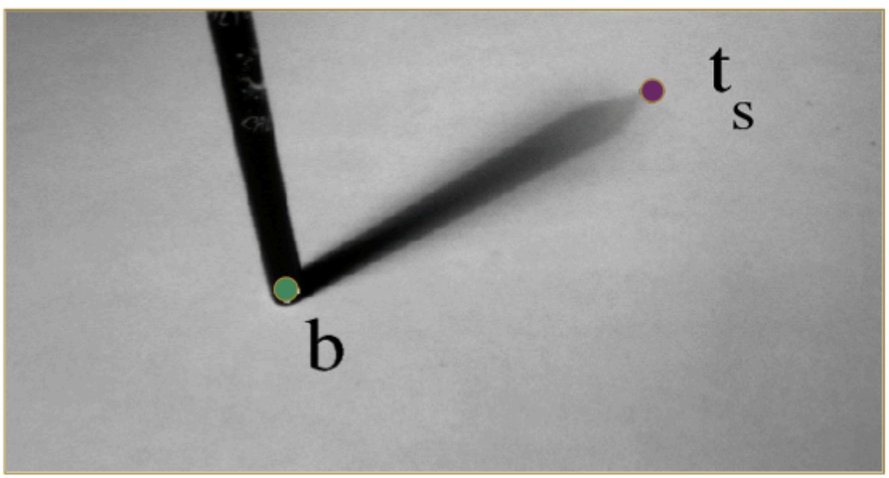


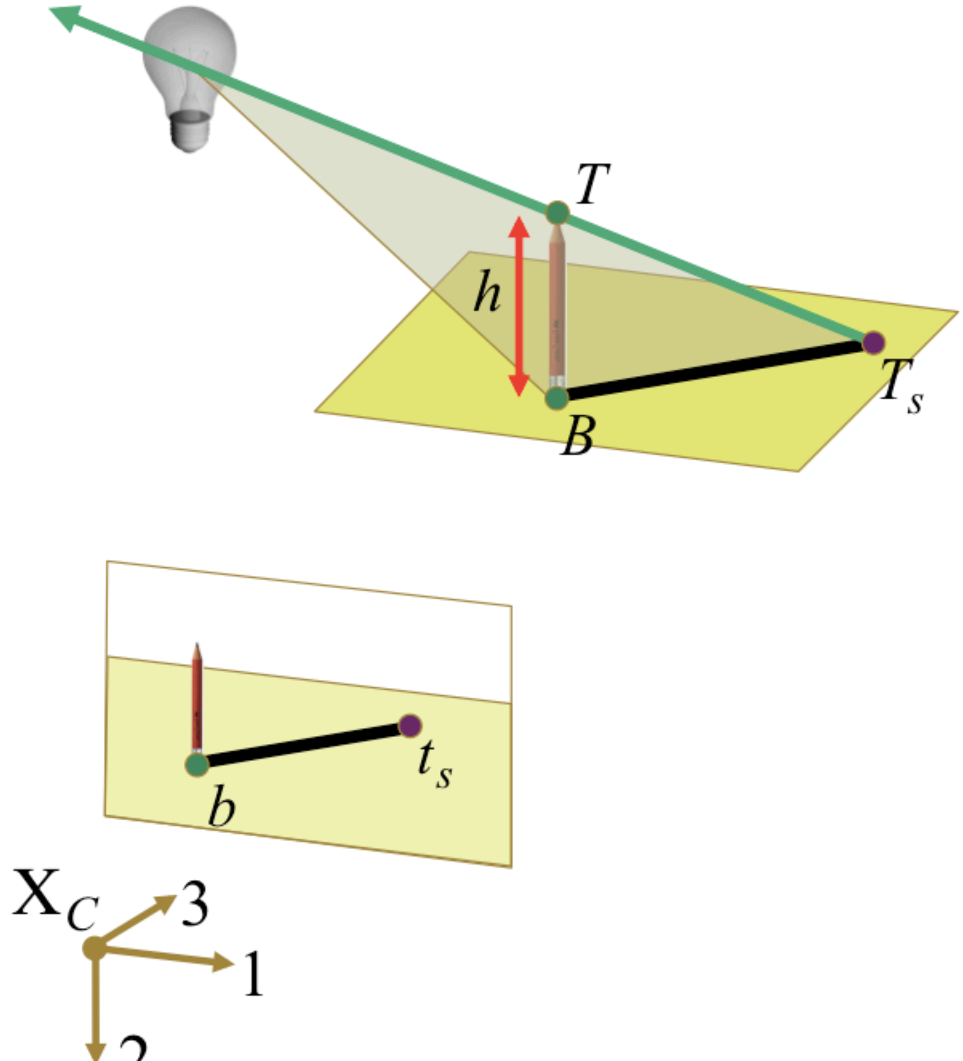


J.-Y. Bouguet and P. Perona. 3D photography on your desk.
Intl. Conf. Comp. Vision, 1998

Alternatives for Shadow Plane Calibration







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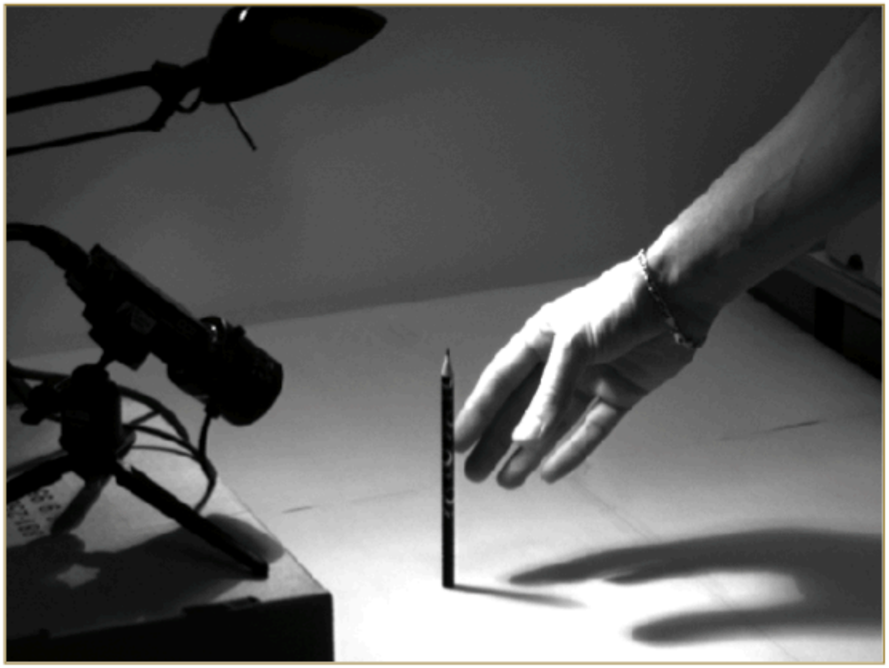
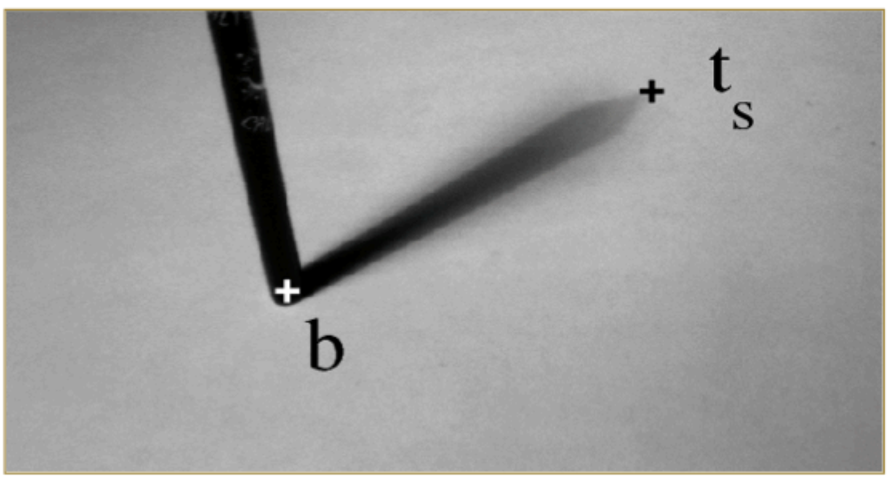
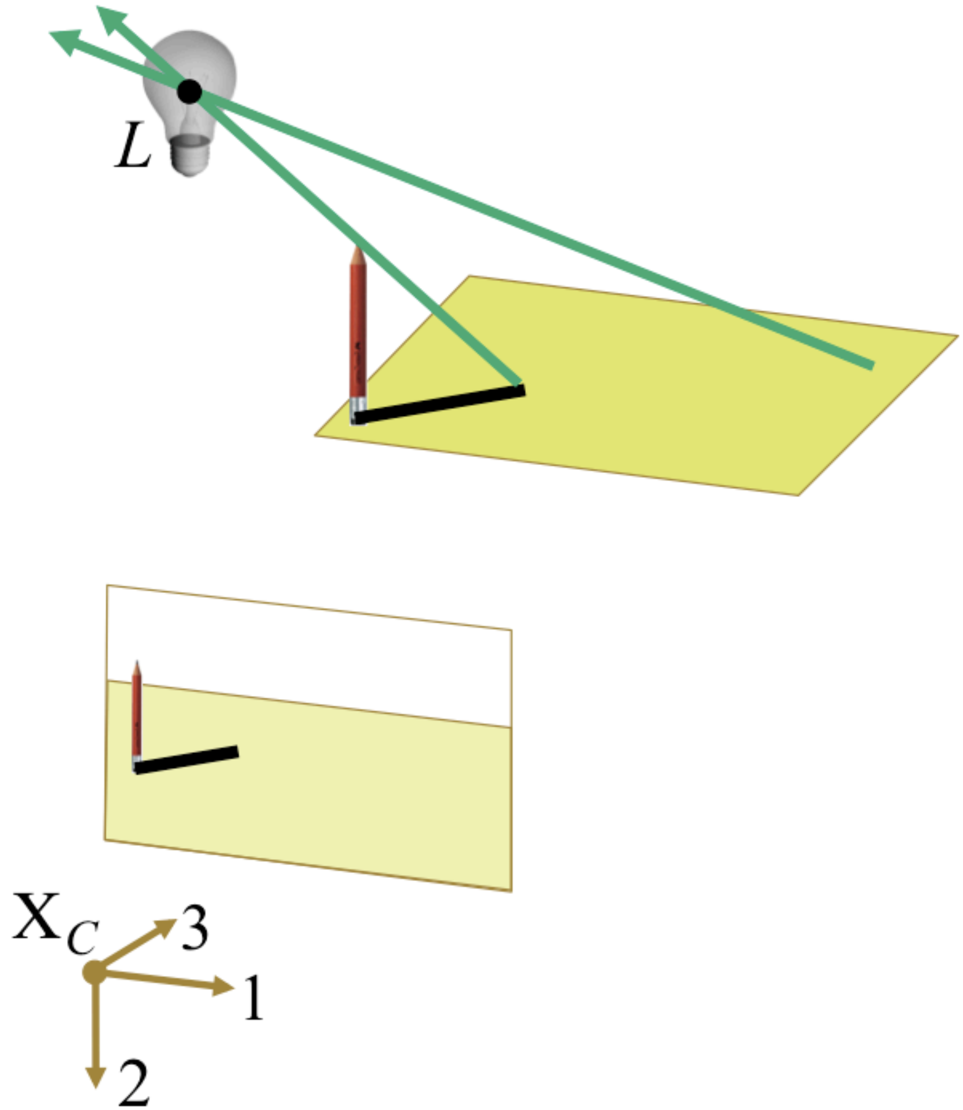
Alternatives for Shadow Plane Calibration

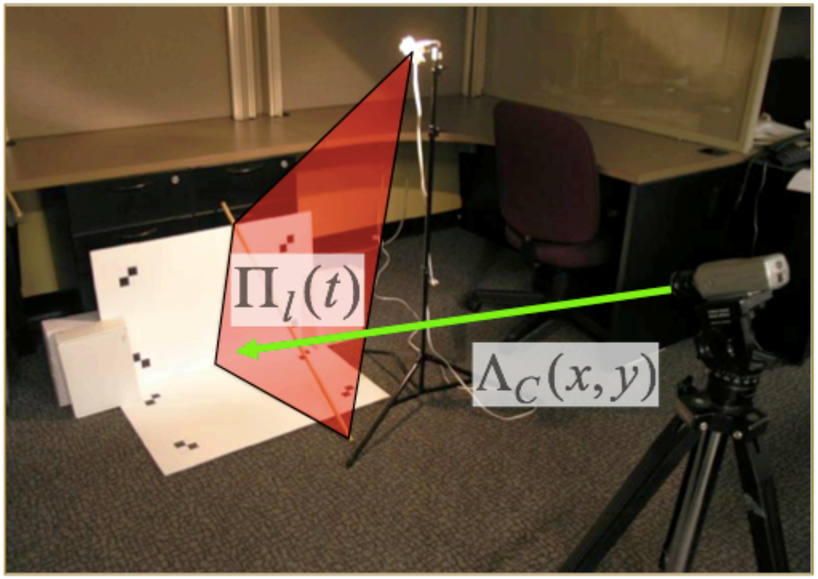


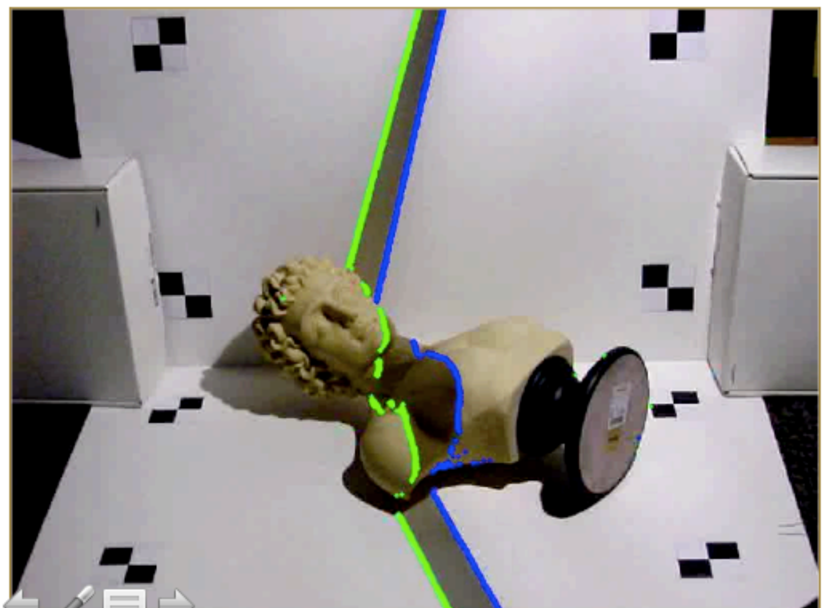


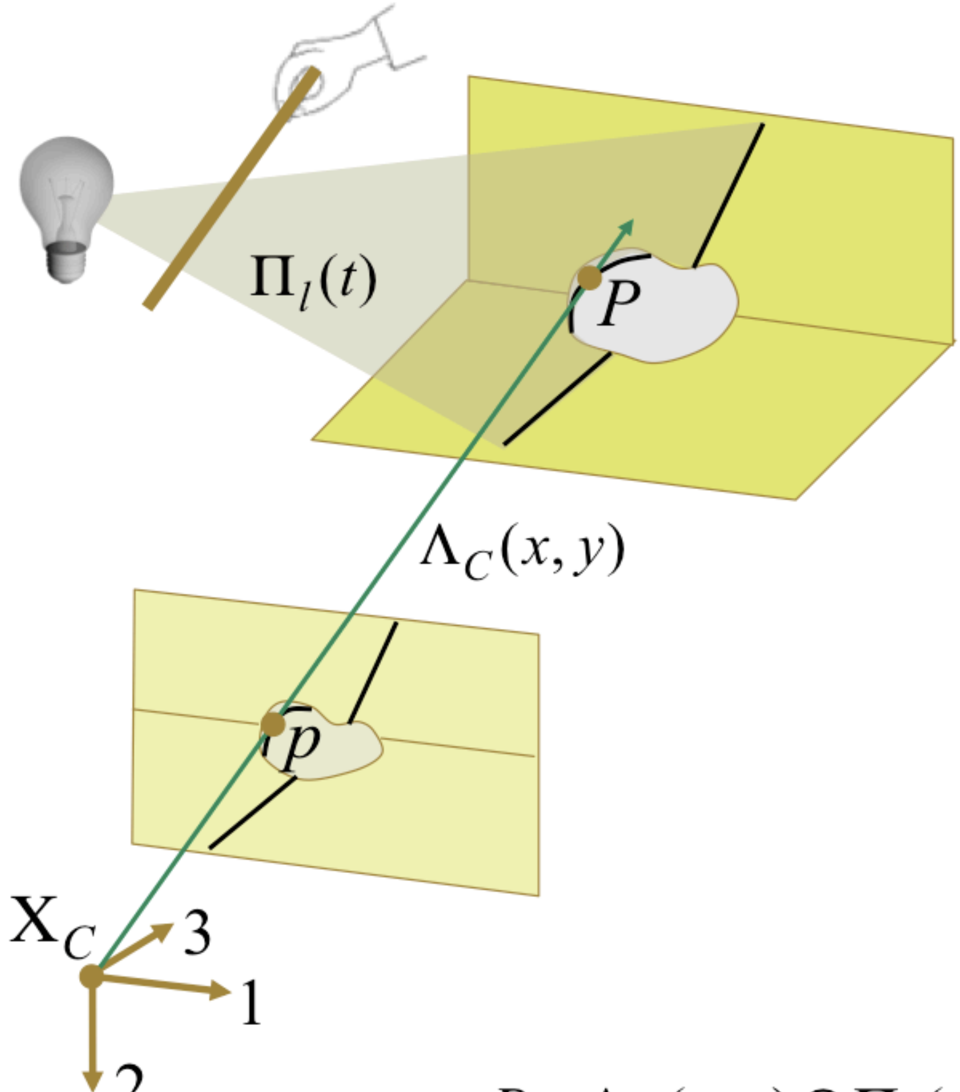


J.-Y. Bouguet and P. Perona. 3D photography on your desk.
Intl. Conf. Comp. Vision, 1998

Point Cloud Reconstruction

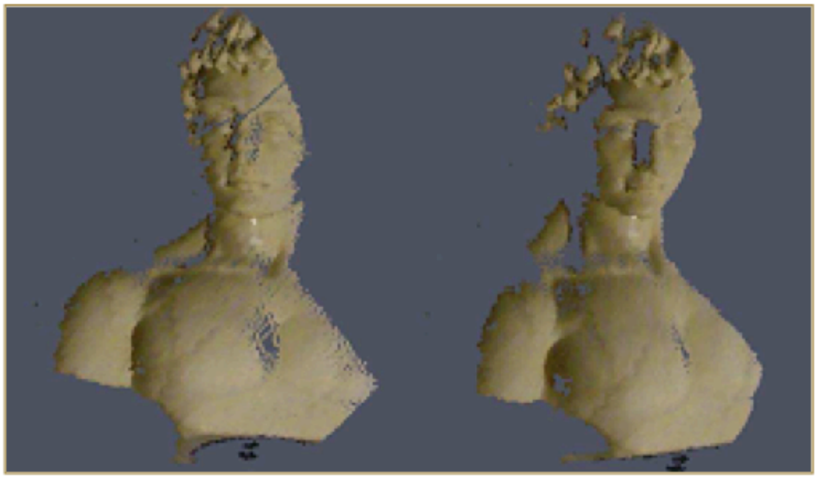


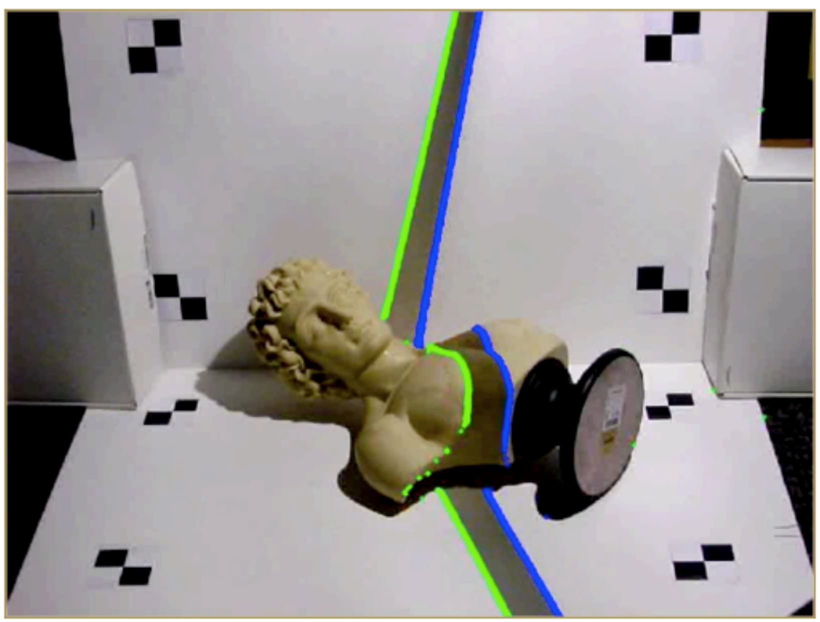


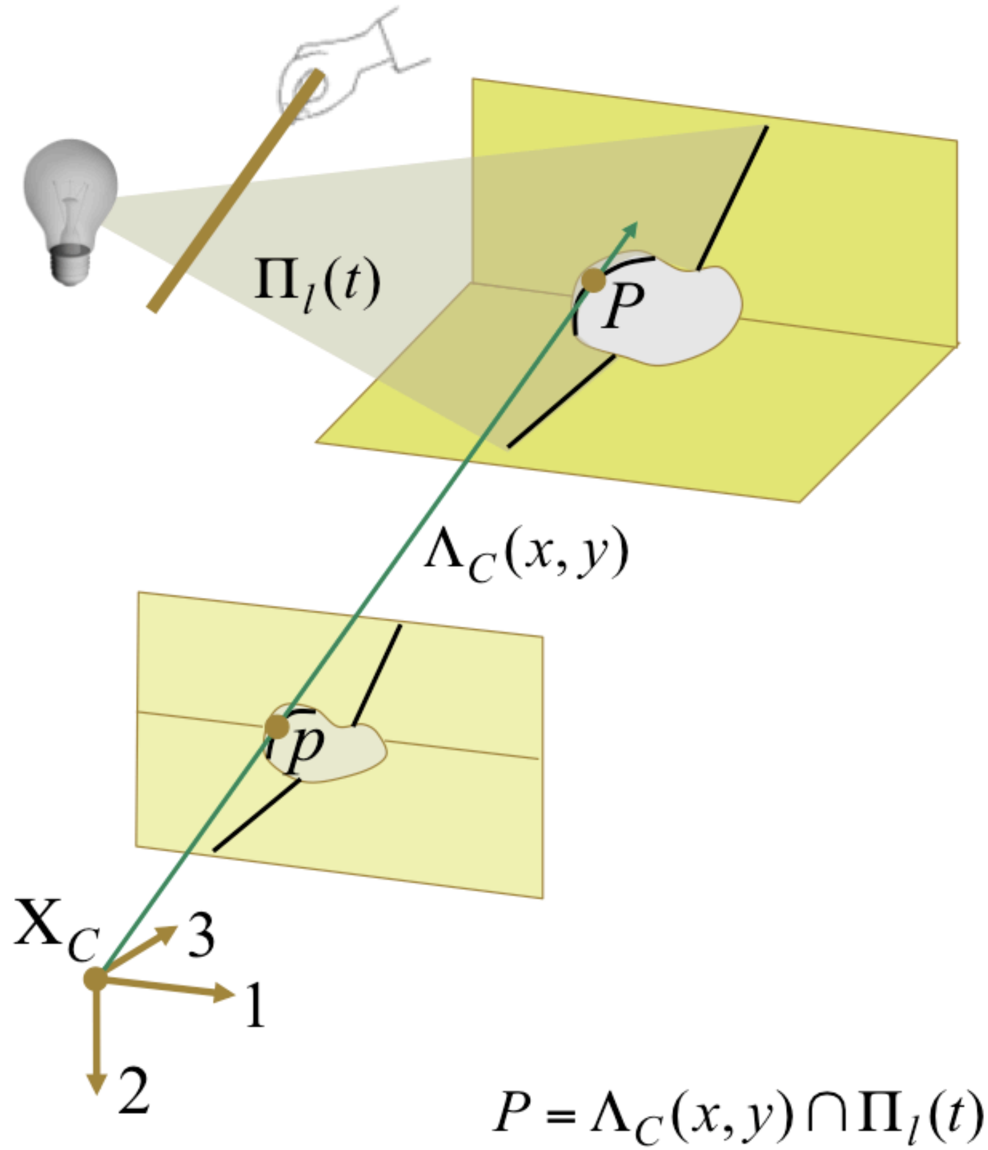


$$P = \Lambda_C(x,y) \cap \Pi_l(t)$$

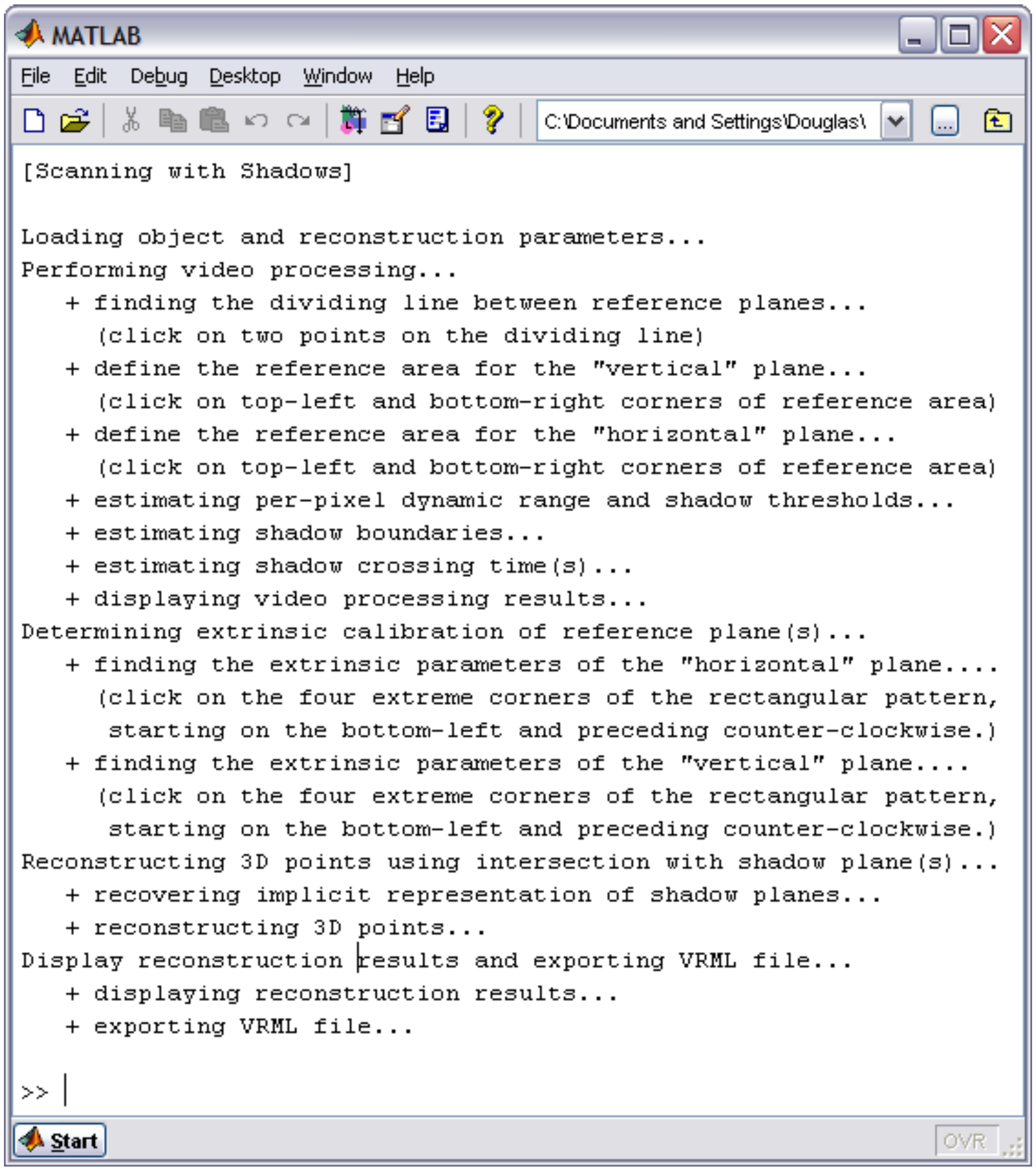
Point Cloud Reconstruction

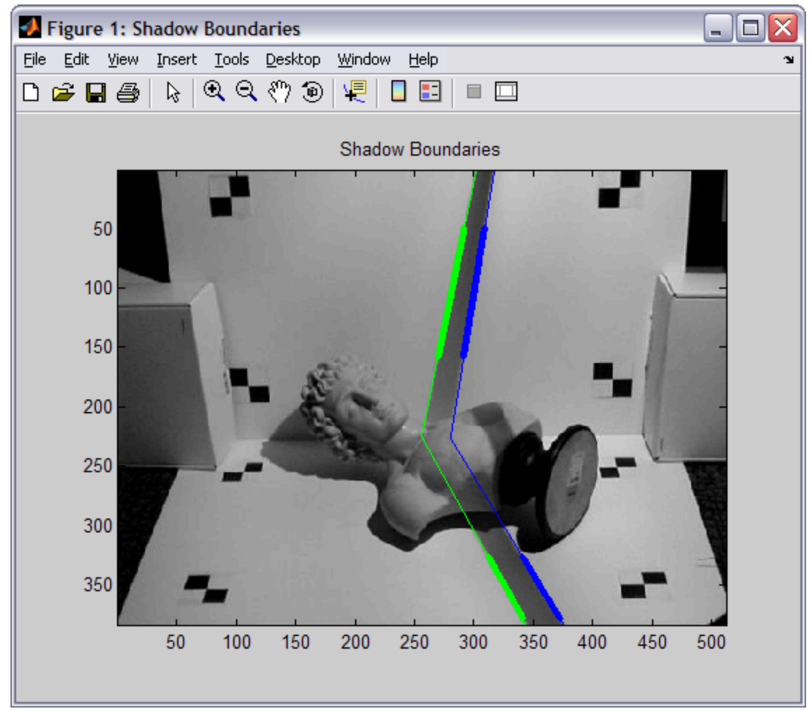






Demo: Putting it All Together





VRML File Format

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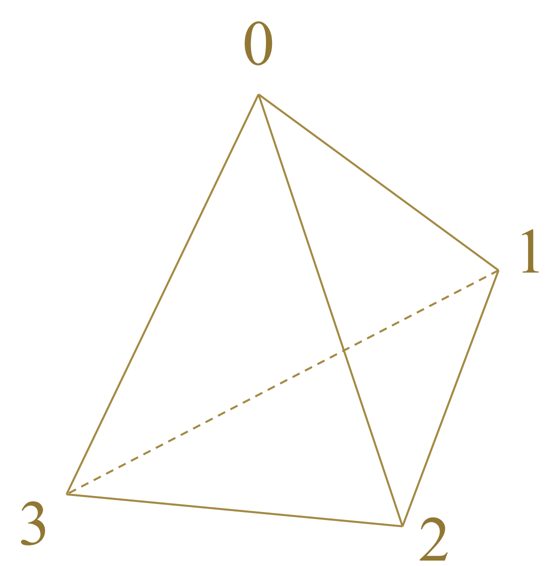
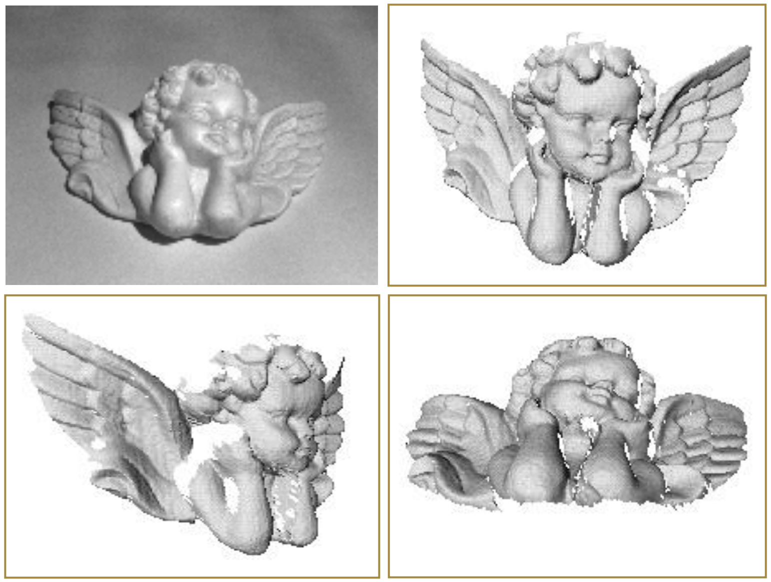
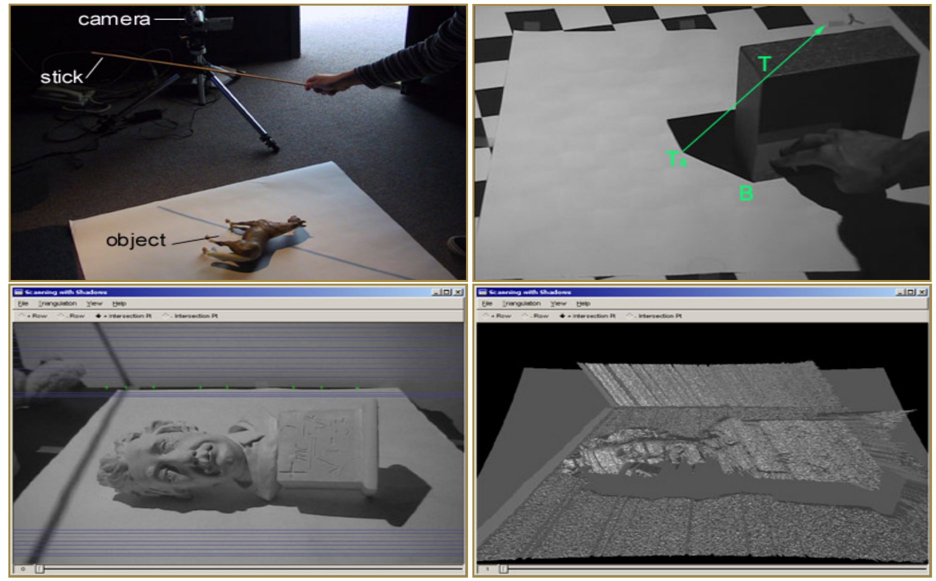
          0.000  0.000  2.000
         -1.633 -0.943 -0.667
          0.000  1.886 -0.667
      ]
    }
    coordIndex [
      0 1 2 -1 3 1 0 -1 2 1 3 -1 2 3 0 -1
    ]
  }
}
```



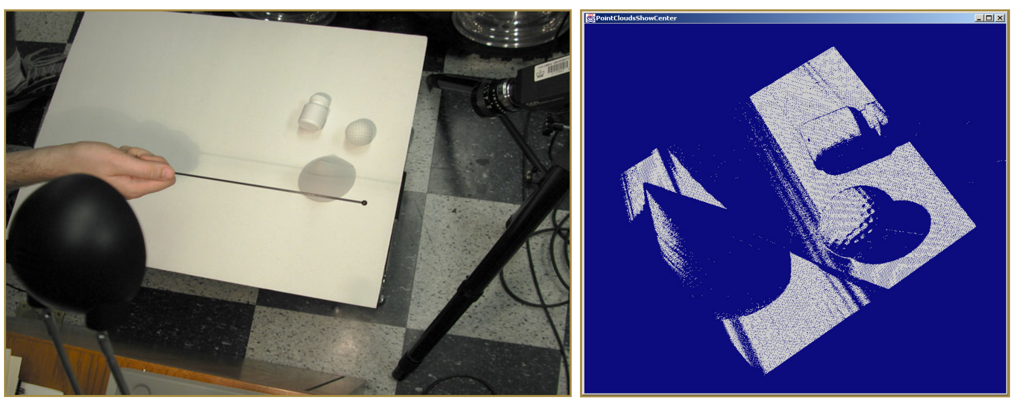
Additional Reconstruction Examples



J.-Y. Bouguet and P. Perona. 3D photography on your desk. *Intl. Conf. Comp. Vision*, 1998



J. Kim and J. Wu. Scanning with Shadows. CSE 558 Project Report (U. Washington), 2001



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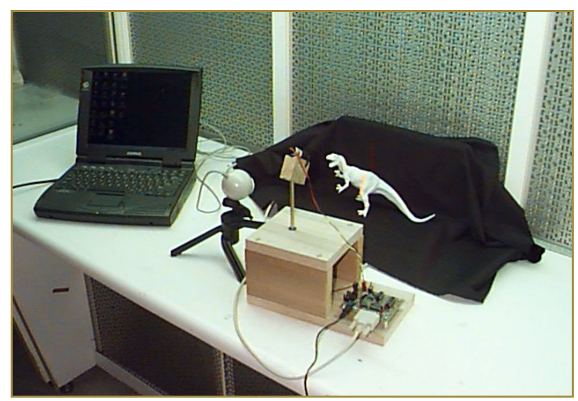

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Course Schedule

- Introduction
- The Mathematics of 3D Triangulation
- 3D Scanning with Swept-Planes
- Camera and Swept-Plane Light Source Calibration
- ***Reconstruction and Visualization using Point Clouds***