# Introducción a la Fotografia 3D

## UBA/FCEN Marzo 27 – Abril 12 2013

## Clase 6 : Martes Abril 9

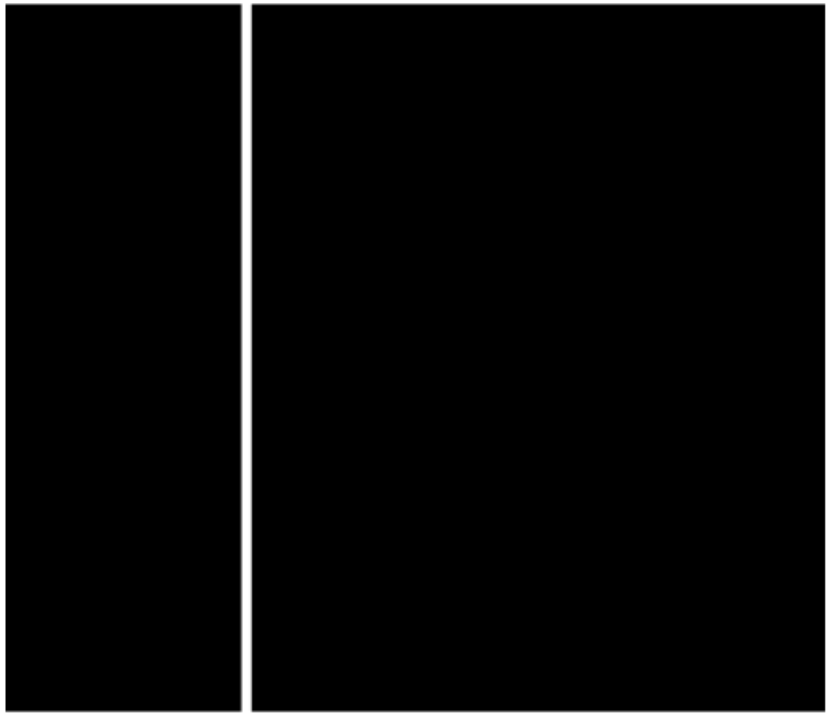
Gabriel Taubin

Brown University

# Course Schedule

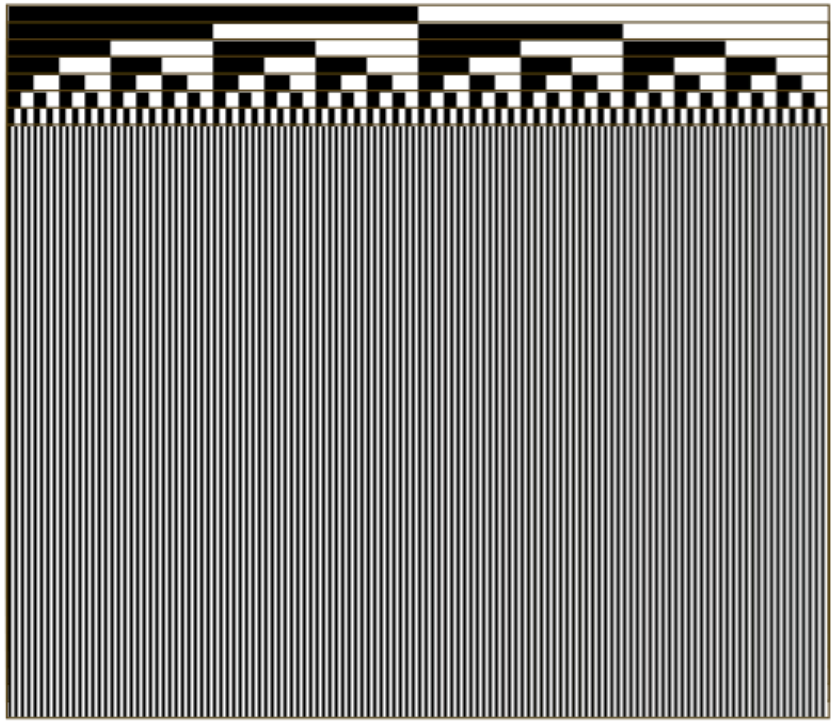
- ***Structured Lighting***
  - Projector Calibration and Structured Light Reconstruction

# Structured Lighting: Swept-Planes Revisited

- Swept-plane scanning recovers 3D depth using ray-plane intersection
- Use a data projector to replace manually-swept laser/shadow planes
- How to assign correspondence from projector planes to camera pixels?
- Solution: Project a spatially- and temporally-encoded image sequence
- **What is the optimal image sequence to project?**

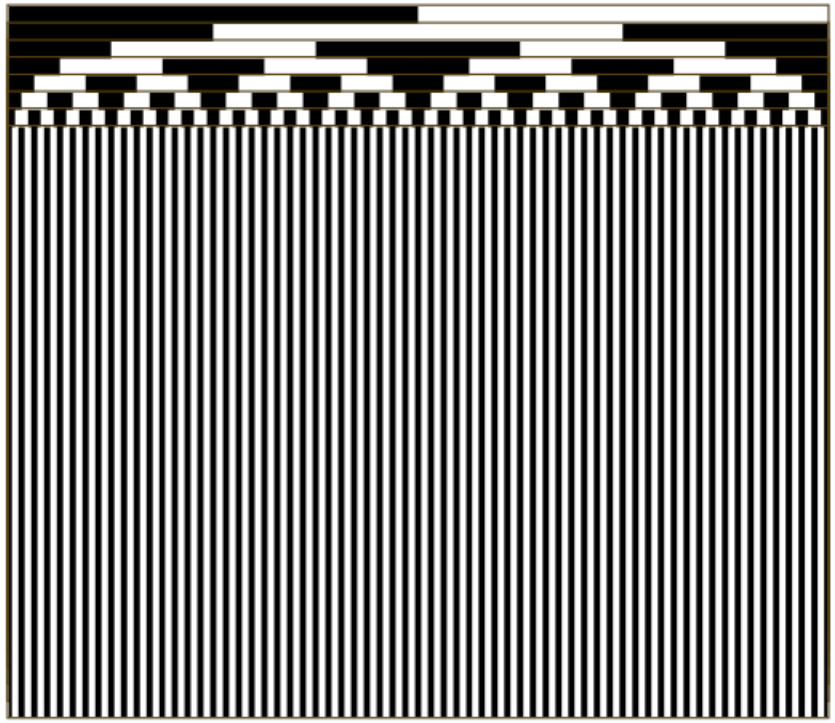
# Structured Lighting: Binary Codes

## Binary Image Sequence [Posdamer and Altschuler 1982]

- Each image is a bit-plane of the binary code for projector row/column
- Minimum of 10 images to encode 1024 columns or 768 rows
- In practice, 20 images are used to encode 1024 columns or 768 rows
- Projector and camera(s) must be synchronized

# Structured Lighting: Gray Codes

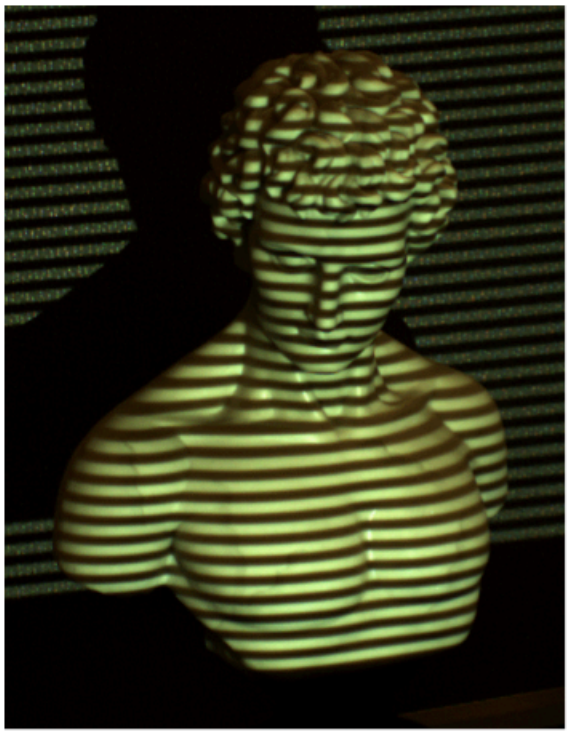



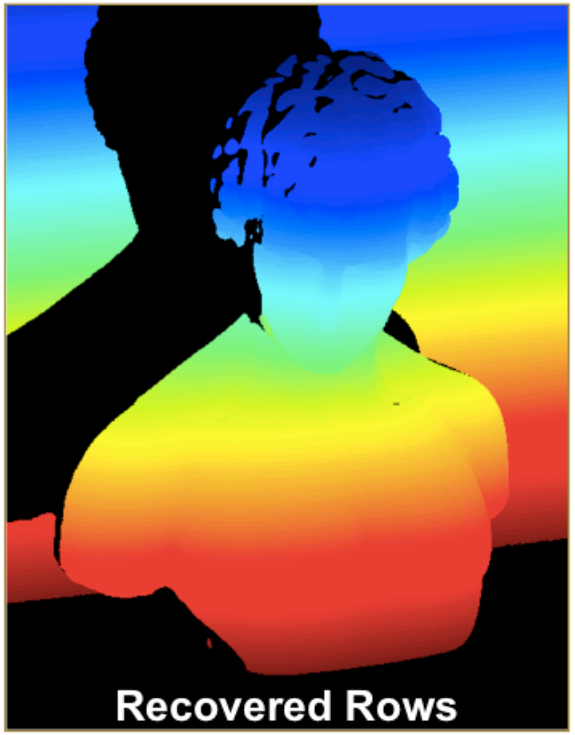
## Gray Code Image Sequence [Inokuchi 1984]

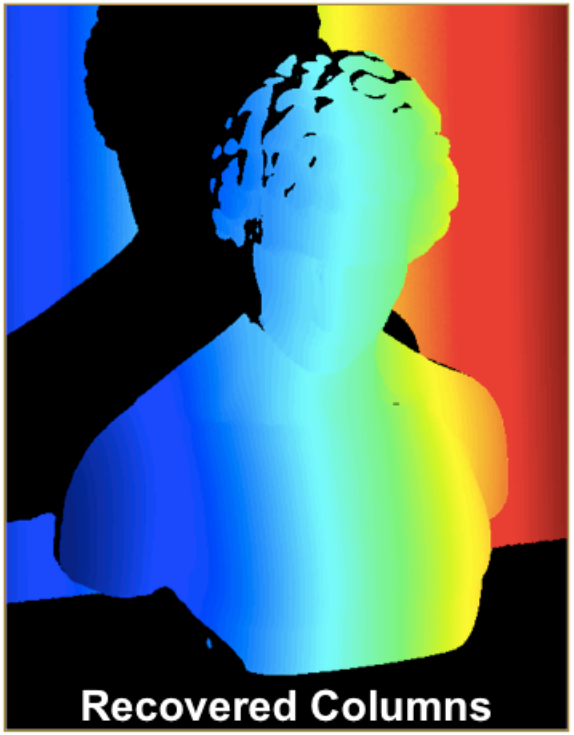
- Each image is a bit-plane of the Gray code for each projector row/column
- Requires same number of images as a binary image sequence, but has better performance in practice

```
Bin2Gray(B,G)
1  G ← B
2  for i ← n-1 downto 0
3      G[i] ← B[i+1] xor B[i]
```

# Gray Codes: Decoding Performance



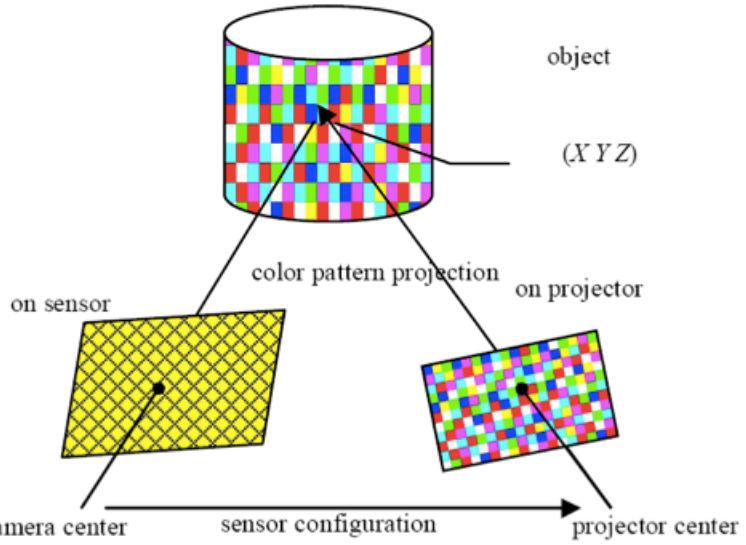


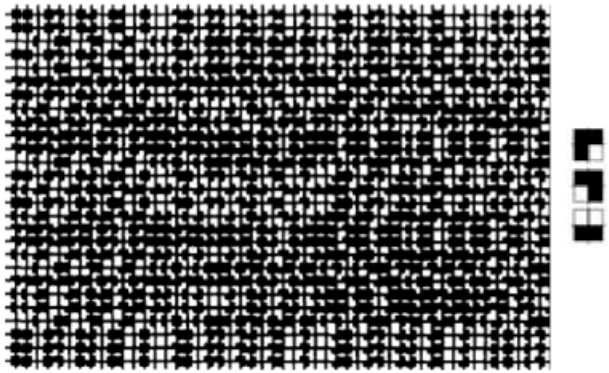

## 3D Reconstruction using Structured Light [Inokuchi 1984]

- Implemented using a total of 42 images
  (2 to measure dynamic range, 20 to encode rows, 20 to encode columns)
- Individual bits assigned by detecting if bit-plane (or its inverse) is brighter
- Decoding algorithm: Gray code → binary code → integer row/column index

# Additional Structured Lighting Patterns



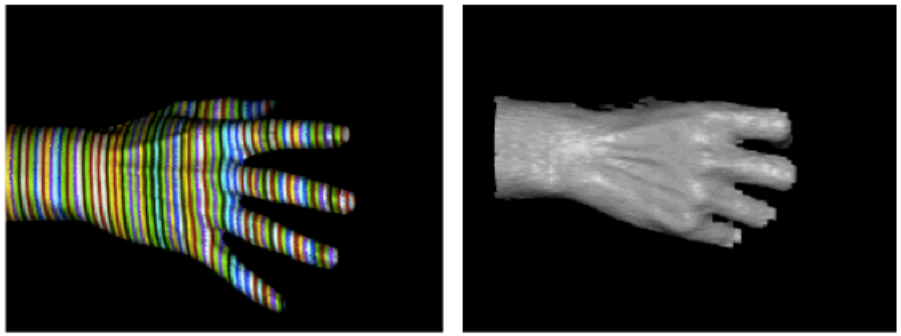

**Spatial encoding strategies [Chen et al. 2007]**



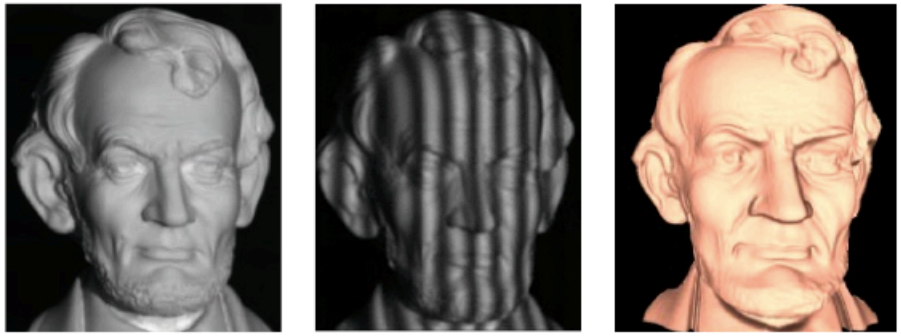
**Pseudorandom and M-arrays [Griffin 1992]**

J. Salvi, J. Pagès, and J. Batlle. Pattern Codification Strategies in Structured Light Systems. *Pattern Recognition*, 2004

**"Single-shot" patterns (N-arrays, grids, random, etc.)**



**De Bruijn sequences [Zhang et al. 2002]**



**Phase-shifting [Zhang et al. 2004]**

# Assembling Your Own Scanner


## Parts List [$600-$800, but only $300 without mounting hardware]

- [1] Camera (Logitech QuickCam Pro 9000) [$70]
- [1] Projector (InFocus LP 70+) [$200-$400 from eBay]
- [1] Manfrotto 190XB 3 Section Aluminum Tripod [$130]
- [1] Manfrotto 486RC2 Compact Ball Head [$75]
- [1] Custom Aluminum Rail (with 3/8 inch holes for mounting ball heads) [NA]
- [1] Custom Aluminum Tripod Adaptor Plate (for mounting projector to ball head) [NA]
- [2] Manfrotto 484 Mini Ball Heads [$45 each]
- [1] Sunpak 620-500C Versipod (with adjustable, locking ball head) [$15]
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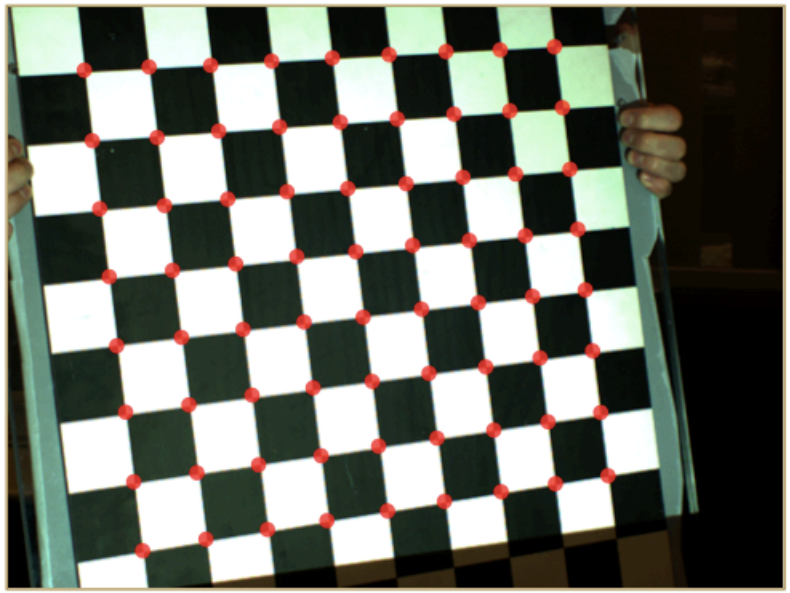
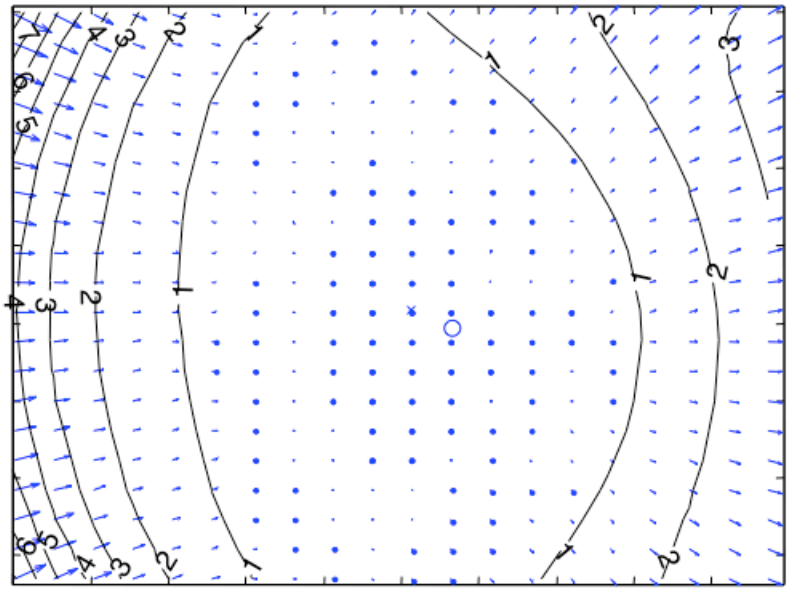
## Key Functions

- Camera and projector calibration





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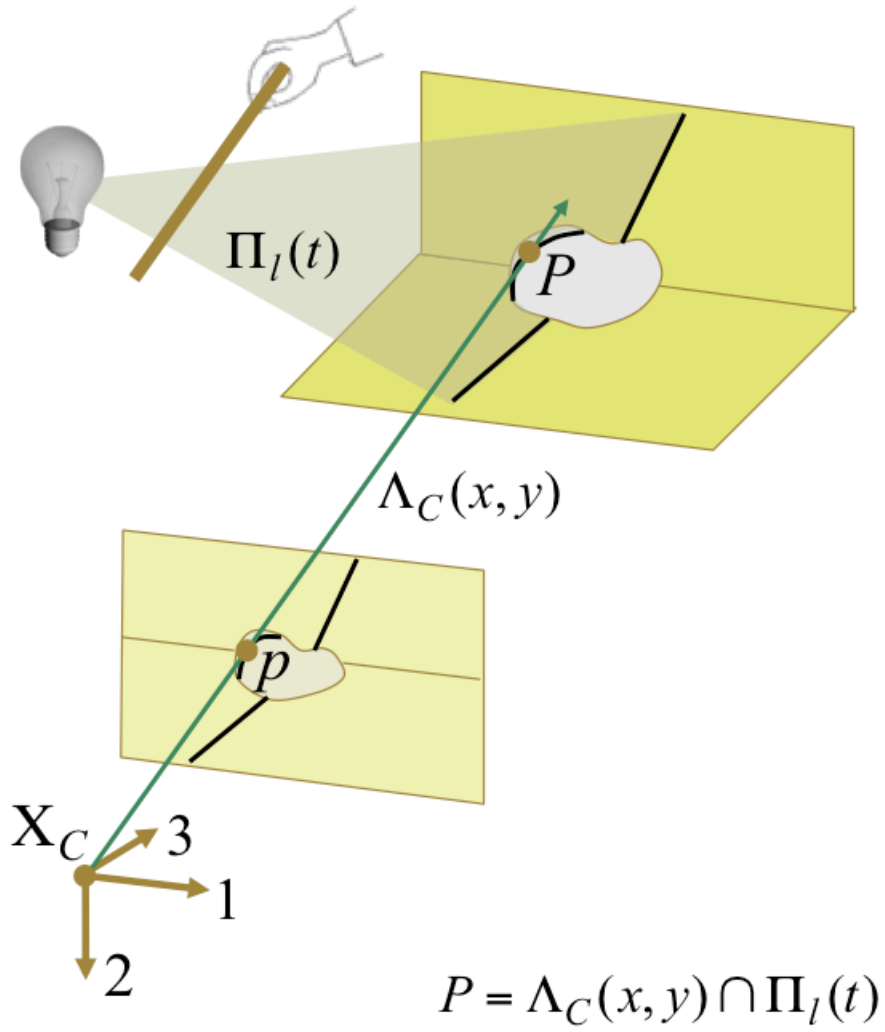

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## Matlab

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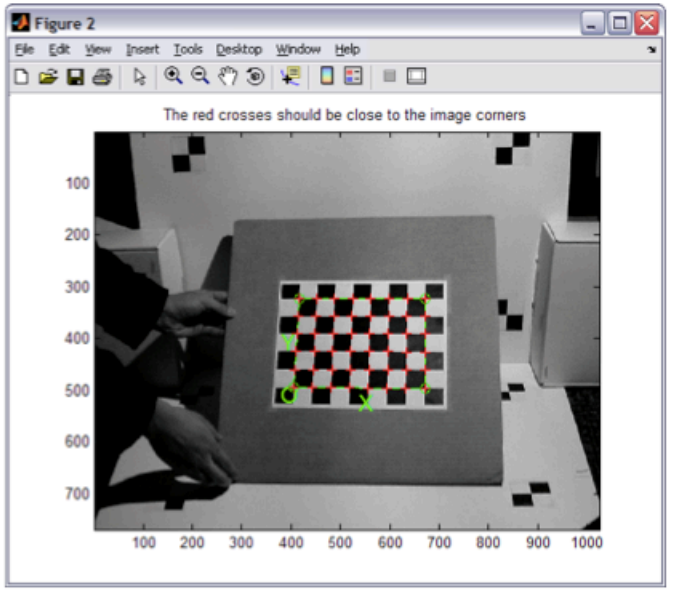


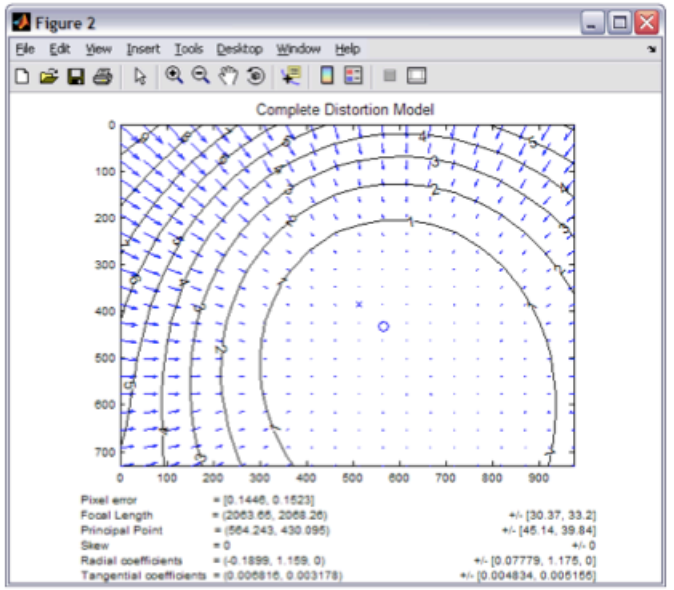

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http://code.google.com/p/procamcalib/

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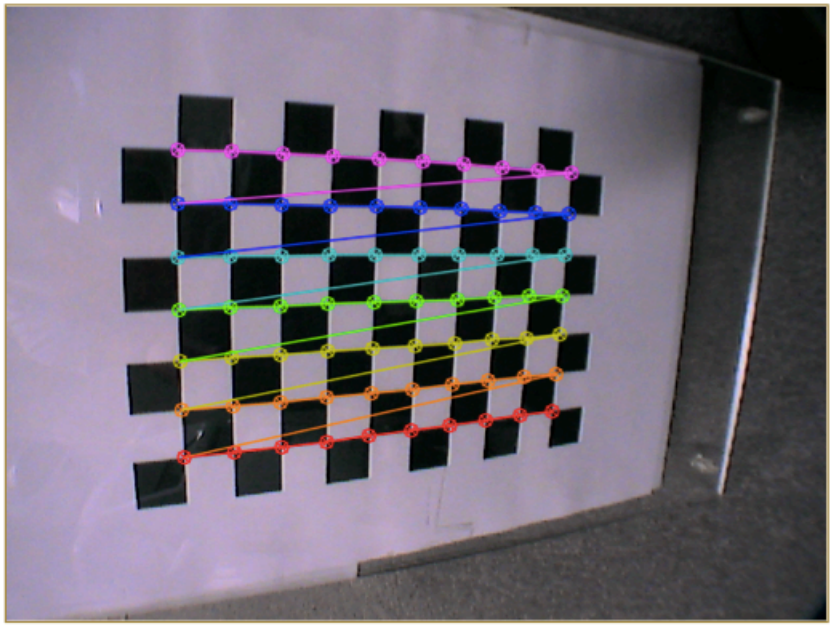

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- Projector-Camera Calibration Toolbox
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- Image Acquisition Toolbox, etc.
- Geometric operations (course source)

**OpenCV**

- Supports camera calibration
- Updated to support projector calibration
  (course source)

http://opencv.willowgarage.com/wiki/

# Controlling a Projector for Structured Lighting

## Operating System

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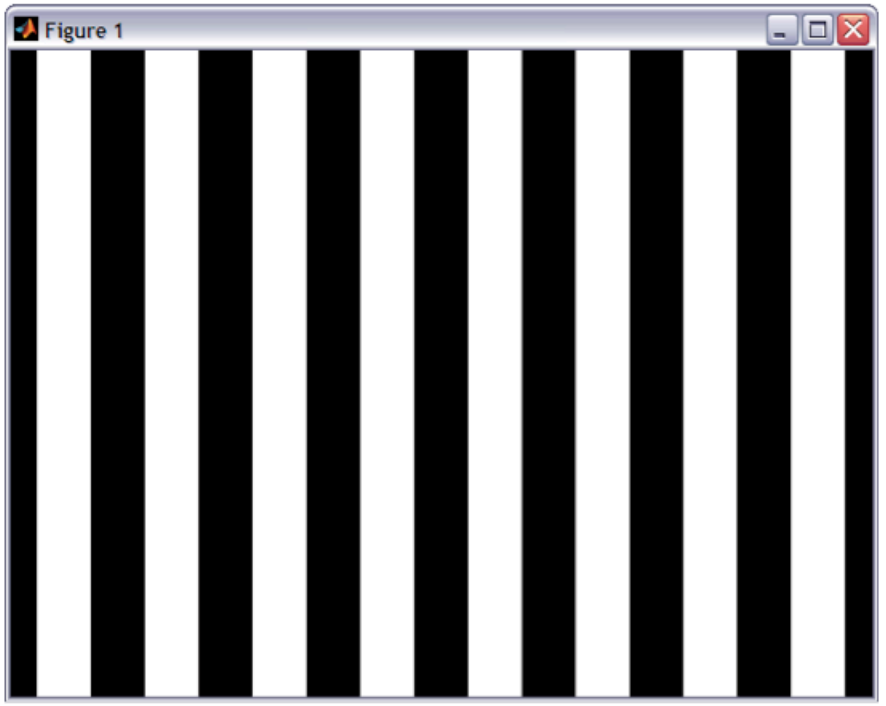
- Fullscreen display not fully supported (cannot remove window decorations)




```
imagesc(P{1}(:,:,5));
axis image off;
set(gca,'Pos',[0 0 1 1]);
set(gcf,'MenuBar','none');
set(gcf,'Pos',[-1023 283 1024 768]);
```

# Controlling a Projector for Structured Lighting

## Operating System

- A projector is just another display…

## Matlab

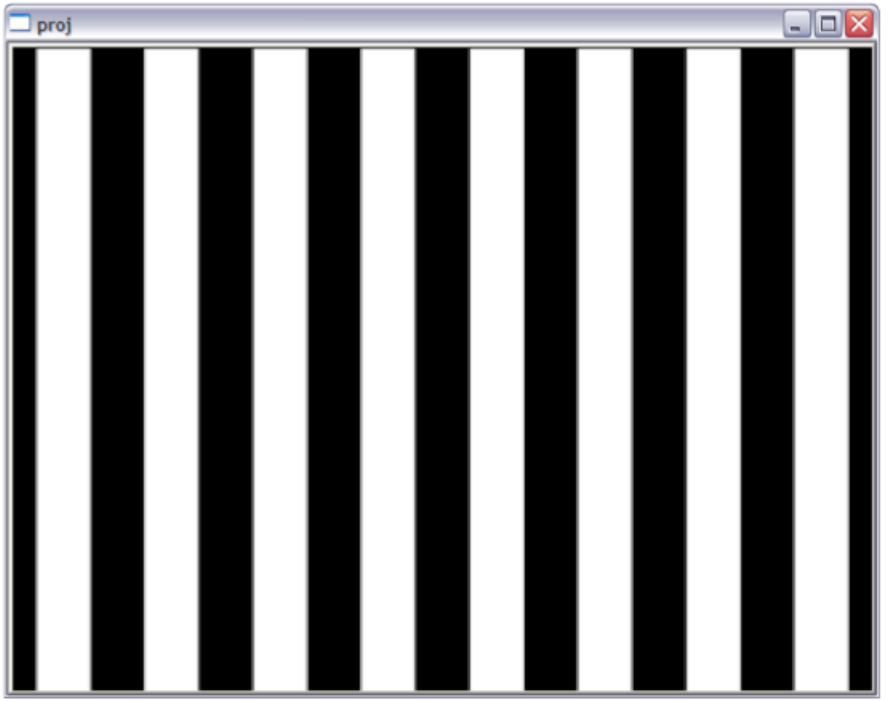
- Fullscreen display not fully supported (cannot remove window decorations)
- Use Java to control displays (slow, multiple display problems)
- Use the *Psychophysics Toolbox* (Screen.m wraps OpenGL functions)

## OpenCV

- Cannot remove window decorations
- cvNamedWindow/cvMoveWindow

## General

- Use OpenGL wrappers



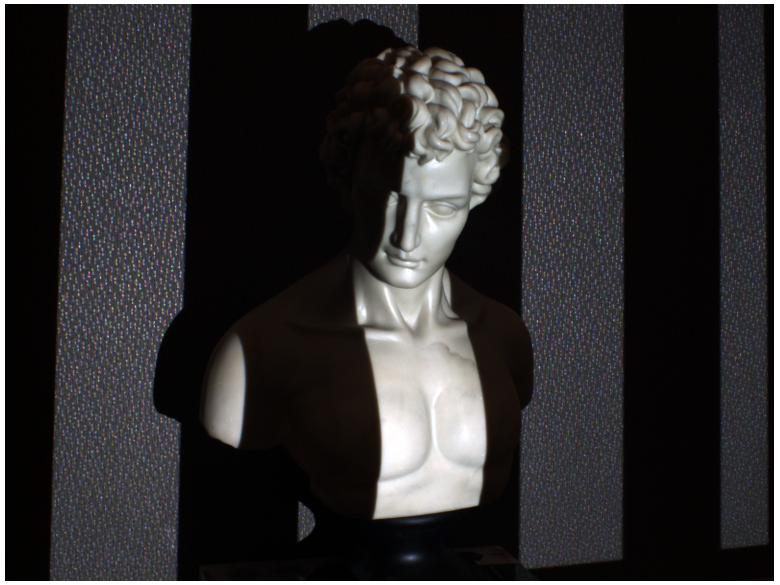

```
cvNamedWindow("proj",CV_WINDOW_AUTOSIZE);
IplImage* proj_frame =
    cvCreateImage(cvSize(w,h),8,3);
cvSet(proj_frame,cvScalar(0,0,0));
cvShowImage("proj",proj_frame);
cvMoveWindow("proj",-w-7,-33);
cvWaitKey(1);
```

http://opencv.willowgarage.com/wiki

# Course Schedule

- Structured Lighting
- ***Robust Pixel Classification***
- Projector Calibration / Structured Light Reconstruction
- Surface Reconstruction from Point Clouds
- Elementary Mesh Processing

# Robust Pixel Classification



- **Robust pixel classification for 3d modeling with structured light**, by Yi Xu and Daniel G. Aliaga, in Proceedings of Graphics Interface 2007, GI ’07, pages 233–240, New York, NY, USA, 2007. ACM.
- **Fast separation of direct and global components of a scene using high frequency illumination**, by Shree K. Nayar, Gurunandan Krishnan, Michael D. Grossberg, and Ramesh Raskar, in ACM Trans. Graph., 25(3):935–944, July 2006.

# Robust Pixel Classification

- The intensity of a pixel can be decomposed into the direct component and indirect (or global) component.
- The direct component is due to light bouncing off the surface in a single reflection.
- The indirect component is due to multiple reflections (e.g. inter-reflections, subsurface, scattering etc.).

$$L(p) = \begin{cases} L_d(p) + \alpha L_g(p) & \text{if p is on} \\ (1-\alpha) L_g(p) & \text{if p is off,} \end{cases}$$

- where $0 \leq \alpha \leq 1$ is a fraction of activated source pixels. For example, for a random binary pattern $\alpha = 1$ , and for a white pattern $\alpha = 1$.

# Robust Pixel Classification

- Estimate direct and global components for each pixel using the method by Nayar
- Use two images of the scene, one with the scene lit with high-frequency illumination, and the other lit with the complementary illumination.

$$L_d(p) = L_{max}(p) - \frac{\alpha}{1-\alpha} L_{min}(p)$$

$$L_g(p) = \frac{1}{1-\alpha} L_{min}(p),$$

# Robust Pixel Classification

- Projecting the code pattern i and its inverse yields two values for each pixel.
- Classify p according to the rules

$$p \text{ is } \begin{cases} \text{uncertain} & \text{if } L_d(p) < m \\ \text{on} & \text{if } L_d(p) > L_g(p) \text{ and } L_i^+(p) > L_i^-(p) \\ \text{off} & \text{if } L_d(p) > L_g(p) \text{ and } L_i^+(p) < L_i^-(p) \\ \text{off} & \text{if } L_i^+(p) < L_d(p) \text{ and } L_i^-(p) > L_g(p) \\ \text{on} & \text{if } L_i^+(p) > L_g(p) \text{ and } L_i^-(p) < L_d(p) \\ \text{uncertain} & \text{otherwise,} \end{cases}$$