



UNIVERSITY OF
SOUTH CAROLINA

CSCE 774 ROBOTICS SYSTEMS

Computer Vision

Slides curtesy of Professor Gregory Dudek



Why vision?

- Passive (emits nothing).
 - Discreet.
 - Energy efficient.
- Intuitive.
- Powerful (works well for us, right?)
- Long and short range.
- Fast.



So, what's the problem?

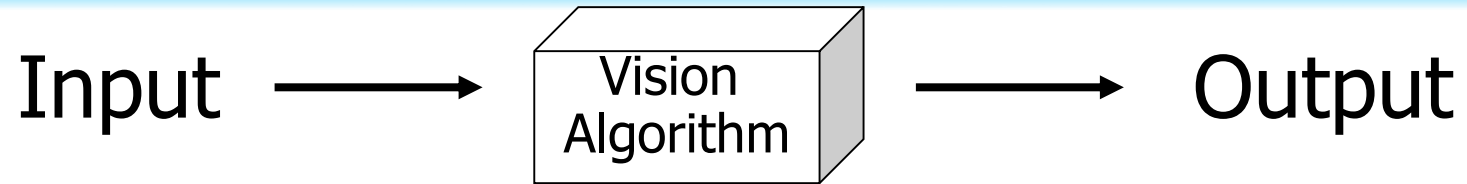
- How hard is vision? Why do we think it is do-able?

Problems:

- Slow.
- Data-heavy.
- Impossible.
- Mixes up many factors.



The “Vision Problem”



The “Vision Problem”

Input



Output

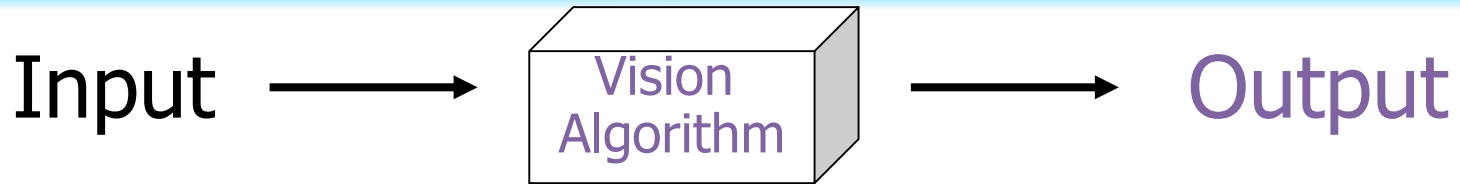
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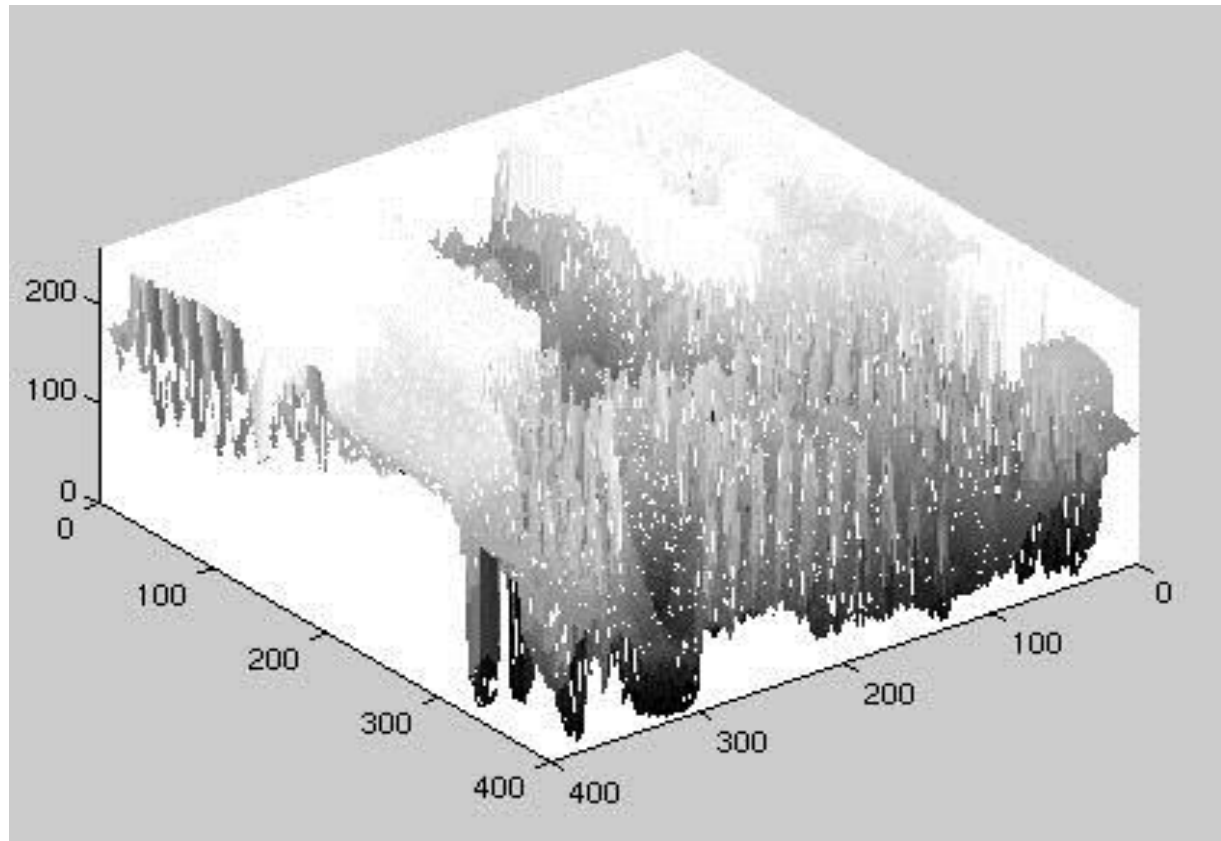
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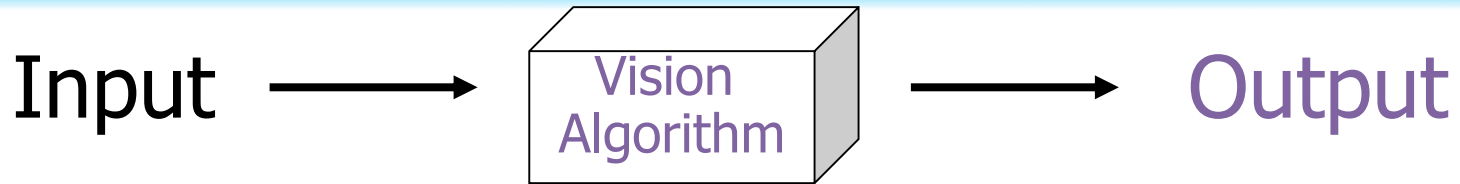
The “Vision Problem”



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The “Vision Problem”



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The “Vision Problem”

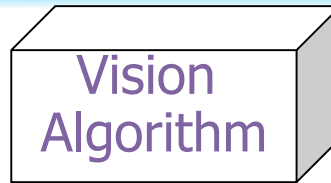


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The “Vision Problem”

Input



Output

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020 067 073 058 055 076 069 050 074 064 065 066 066 059 023
047 109 107 118 107 115 110 120 120 124 120 128 124 132 131
047 125 130 130 122 121 117 142 131 133 134 141 149 144 135
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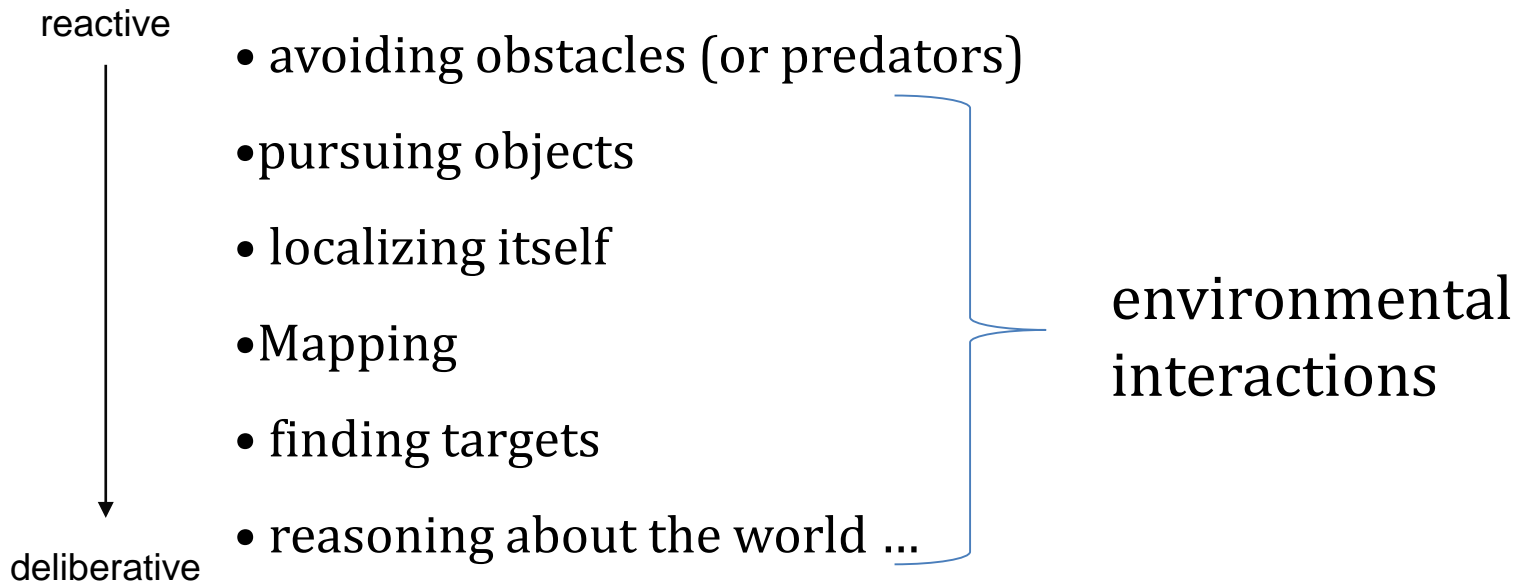
What does a robot need ?

doesn't need a full interpretation of available images

“This is Prof. X in his office offering me a can of spam.”

does need information about what to do...

“Run Away!!”



What does a robot need ?

- What a camera does to the 3d world...

Shigeo Fukuda



squeezes away one dimension

[http://www.psychologie.tu-dresden.de/i1/kaw/diverses Material/www.illusionworks.com/html/art_of_shigeo_fukuda.html](http://www.psychologie.tu-dresden.de/i1/kaw/diverses%20Material/www.illusionworks.com/html/art_of_shigeo_fukuda.html)



What does a robot need ?

- What a camera does to the 3d world...

Shigeo Fukuda



http://www.psychologie.tu-dresden.de/i1/kaw/diverses/Material/www.illusionworks.com/html/art_of_shigeo_fukuda.html



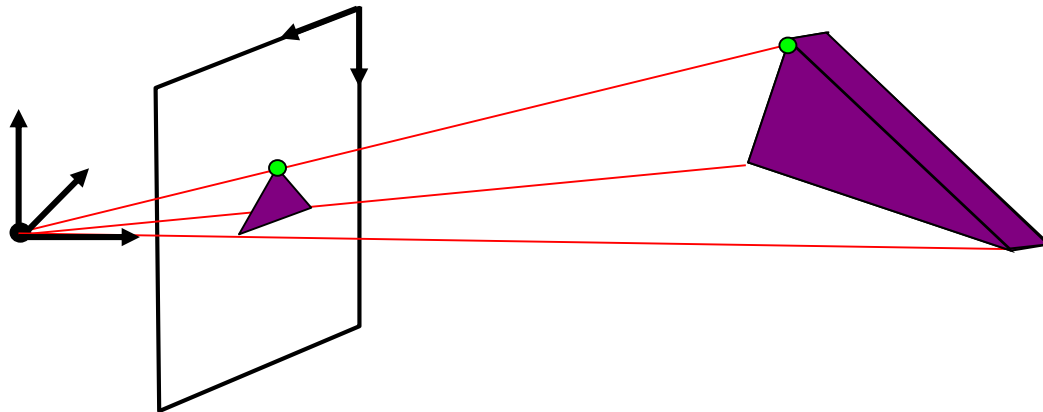
Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.



The vision problem in general...

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.
- Basically, there are too many possible worlds that might (in theory) give rise to a particular image



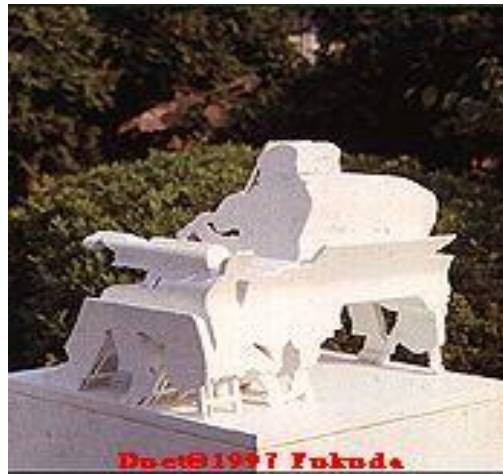
Ill-posed

- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.



Ill-posed

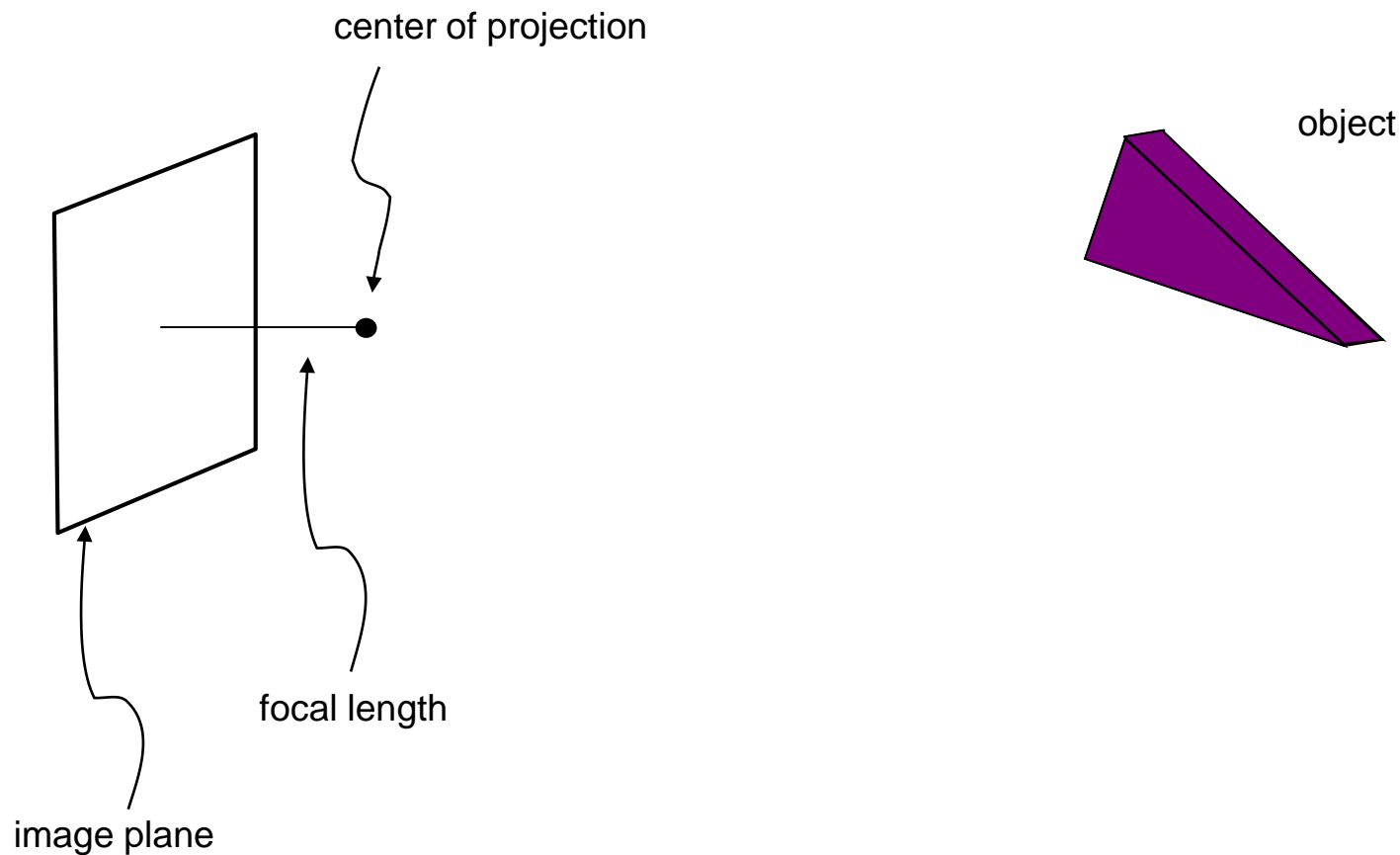
- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.



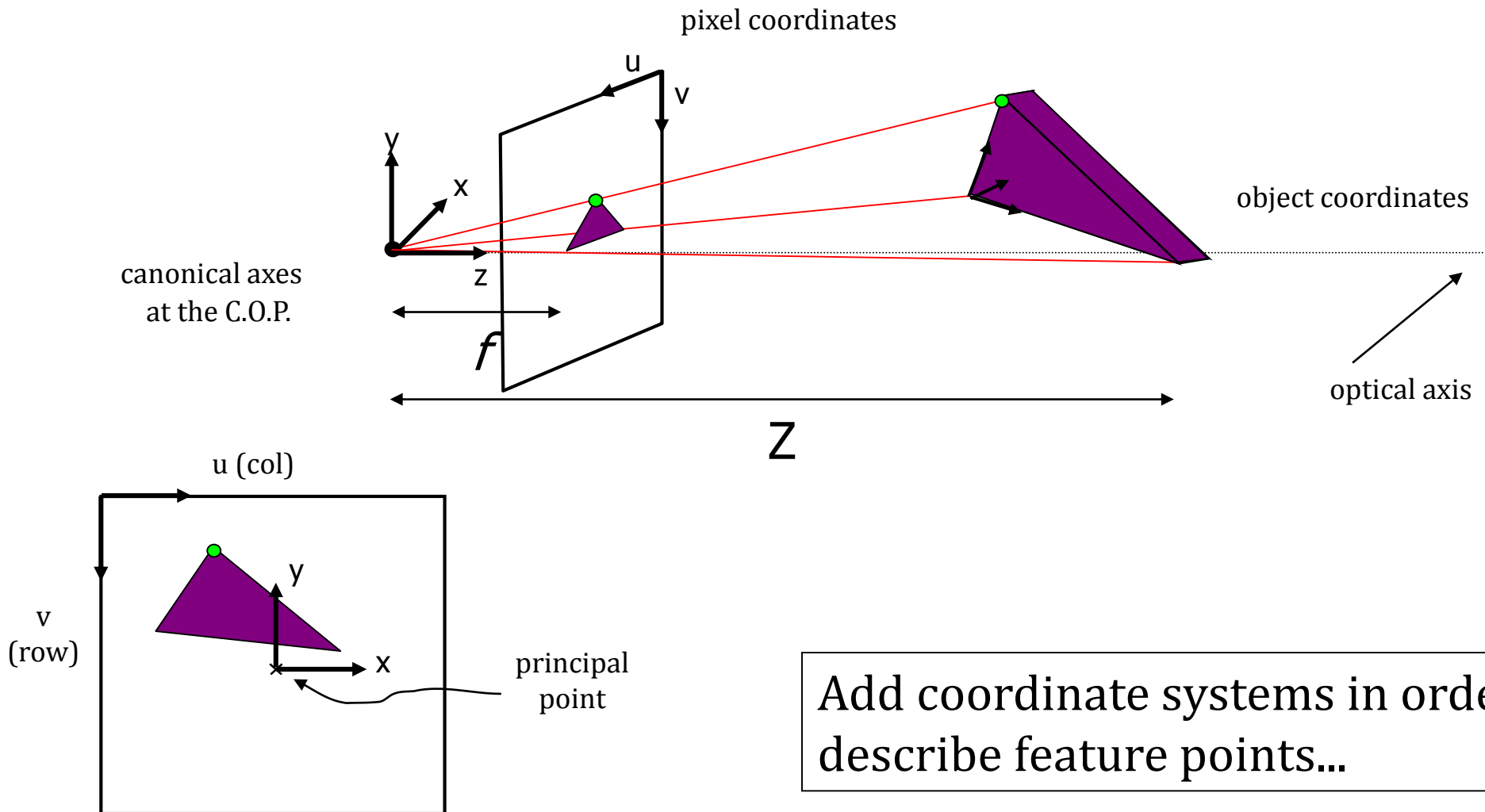
- An image isn't enough to disambiguate the many possible 3d worlds that could have produced it.

Camera Geometry

3D \rightarrow 2D transformation: perspective projection



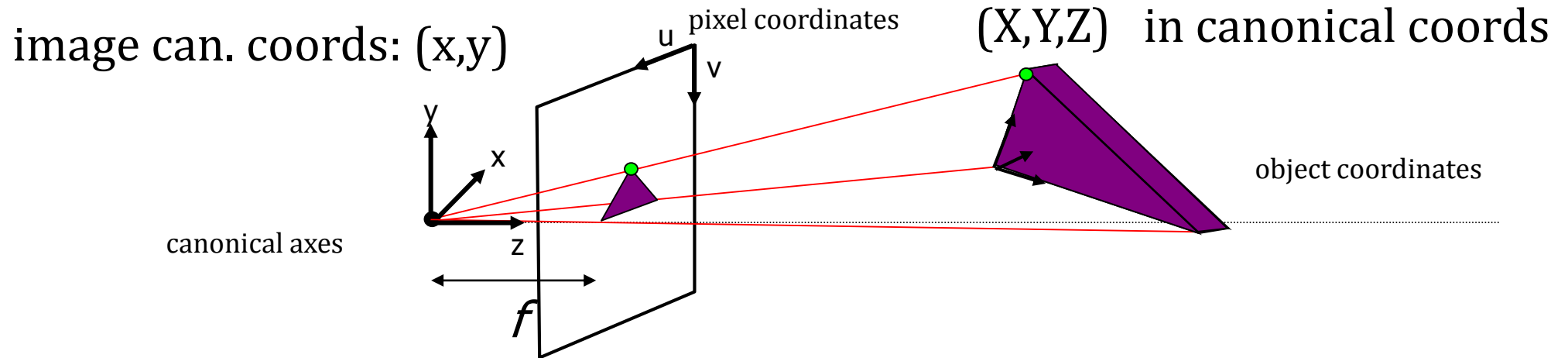
Coordinate Systems



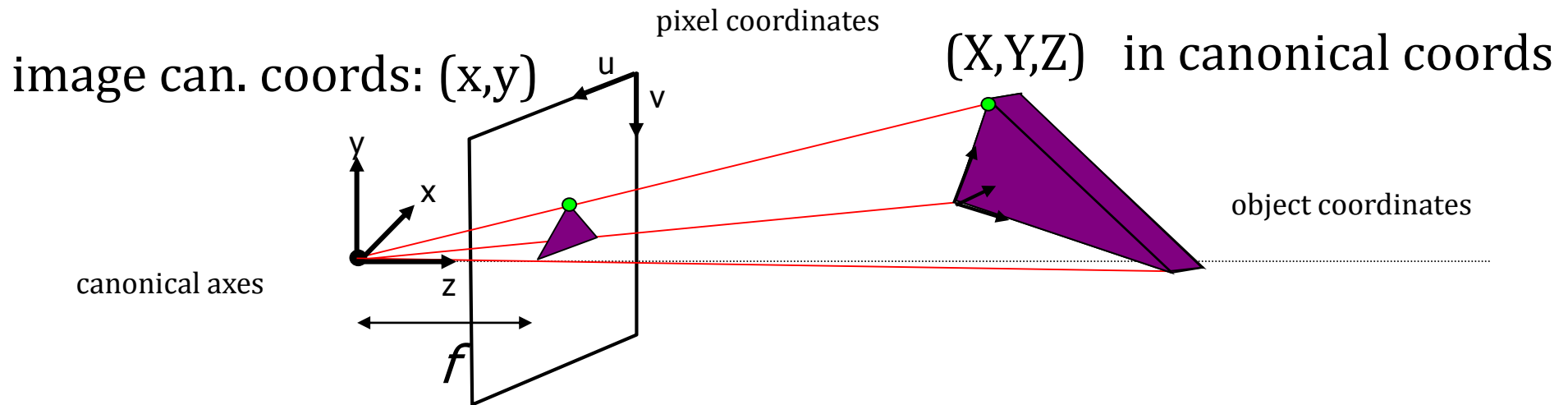
Add coordinate systems in order to describe feature points...



Coordinate Systems



From 3d to 2d



$$x = \frac{fX}{Z}$$

$$y = \frac{fY}{Z}$$

a nonlinear transformation

goal: to recover information about (X,Y,Z) from (x,y)

Camera Calibration

- Camera Model

- $[u \ v \ 1]$ Pixel coords

- $[x_w \ y_w \ z_w \ 1]^T$ World coords

$$z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A [R \ T] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

- Intrinsic Parameters

- $\alpha_x = f \cdot m_x, \alpha_y = f \cdot m_y$ focal lengths in pixels

- γ skew coefficient

- u_0, v_0 focal point

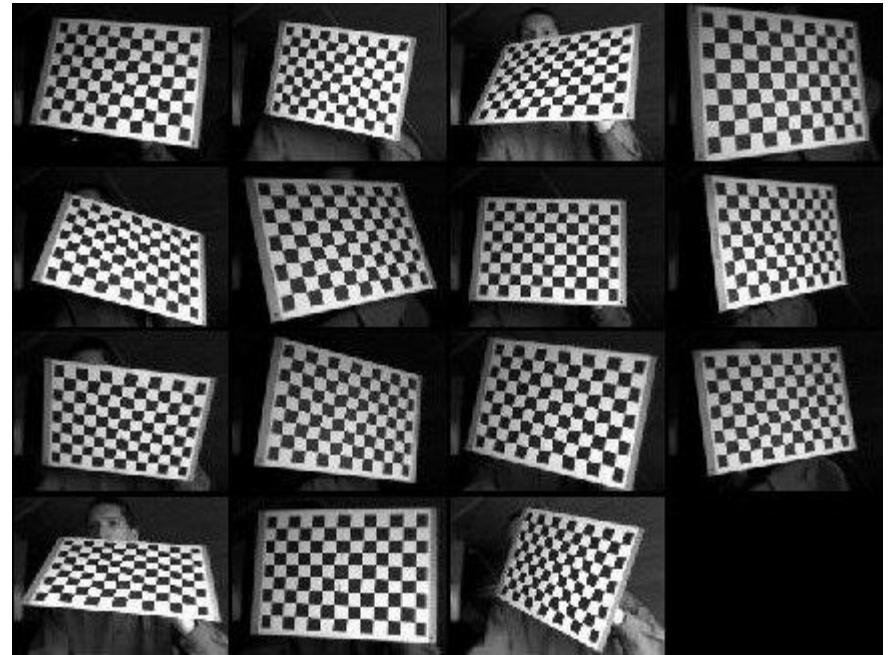
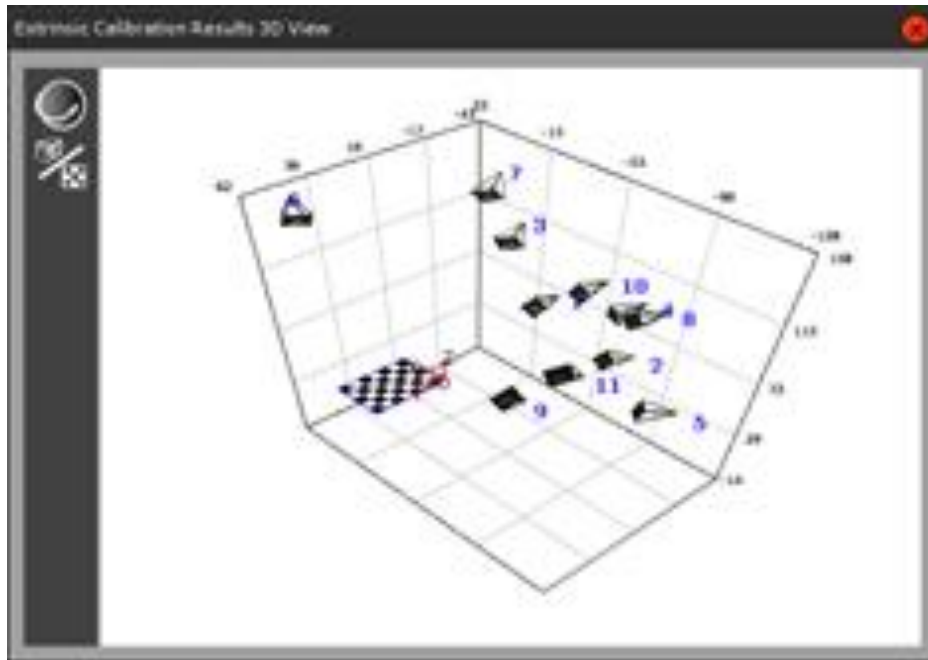
$$A = \begin{bmatrix} \alpha_x & \gamma & u_0 \\ 0 & \alpha_y & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

- Extrinsic Parameters

- $[R \ T]$ Rotation and Translation



Camera Calibration



Existing packages in MATLAB, OpenCV, etc

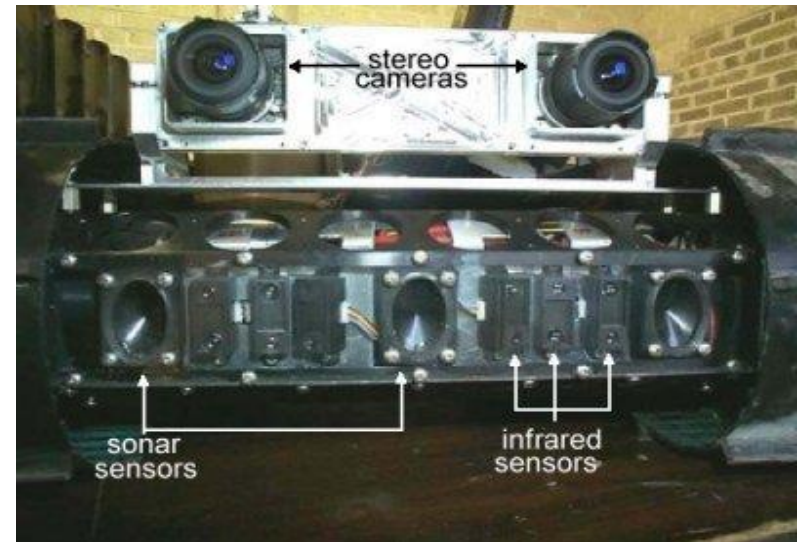


A Vision “solution”

- If interpreting a single image is difficult... What about more ?!



multiple cameras

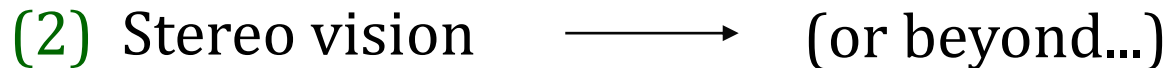
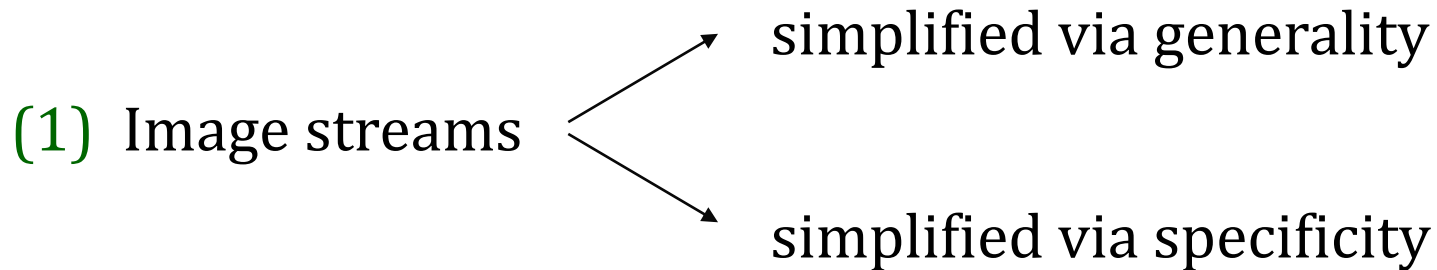


multiple times



Robot vision sampler

A brief overview of robotic vision processing...



(3) Incorporating vision within robot control

↓
3d reconstruction

↓
Visual “servoing”

speaking of servoing...



Visual Servoing

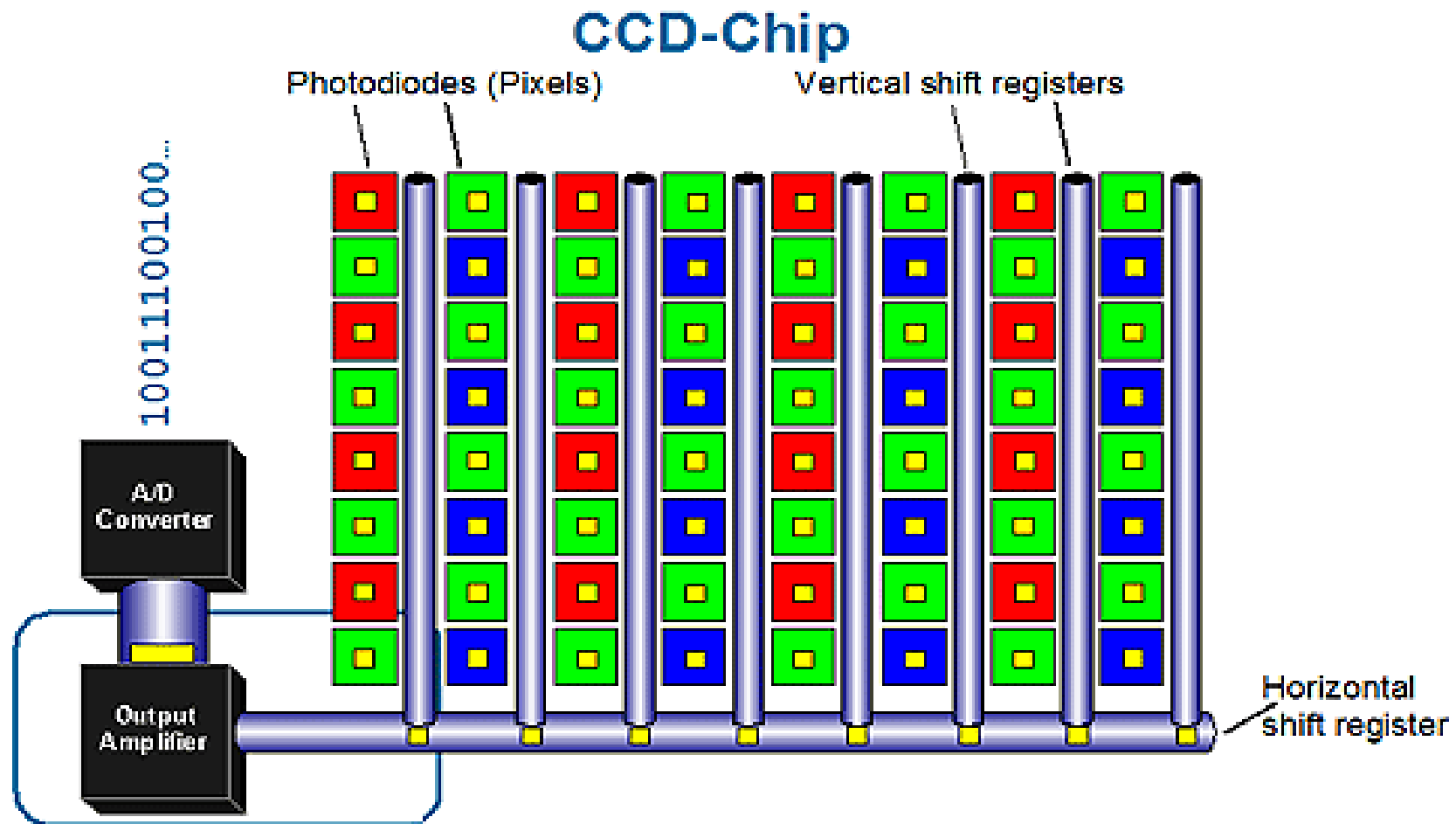


Details

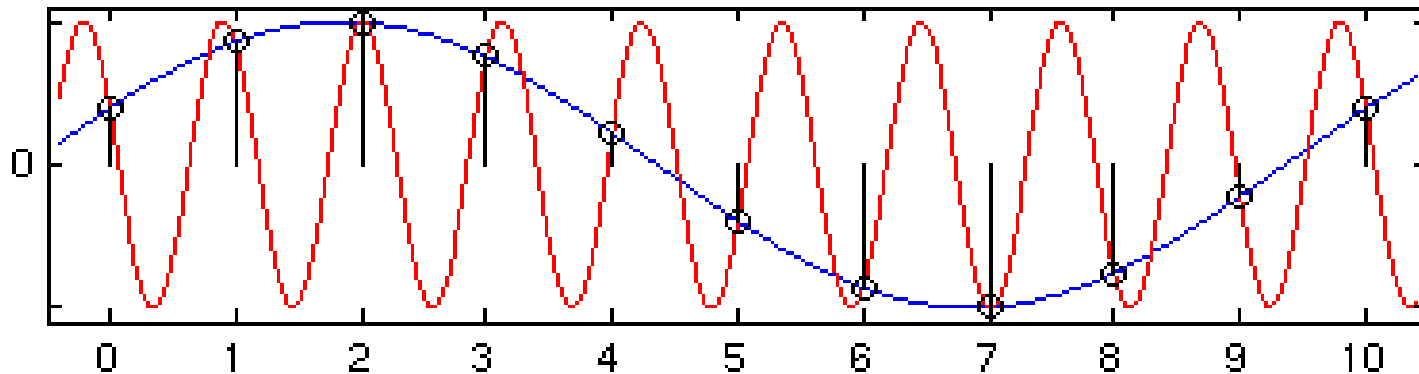
- Images are not actually continuous.
- The sampling (and hardware) issues lead to a few other minor problems.



CCD (Charge-Coupled Device)



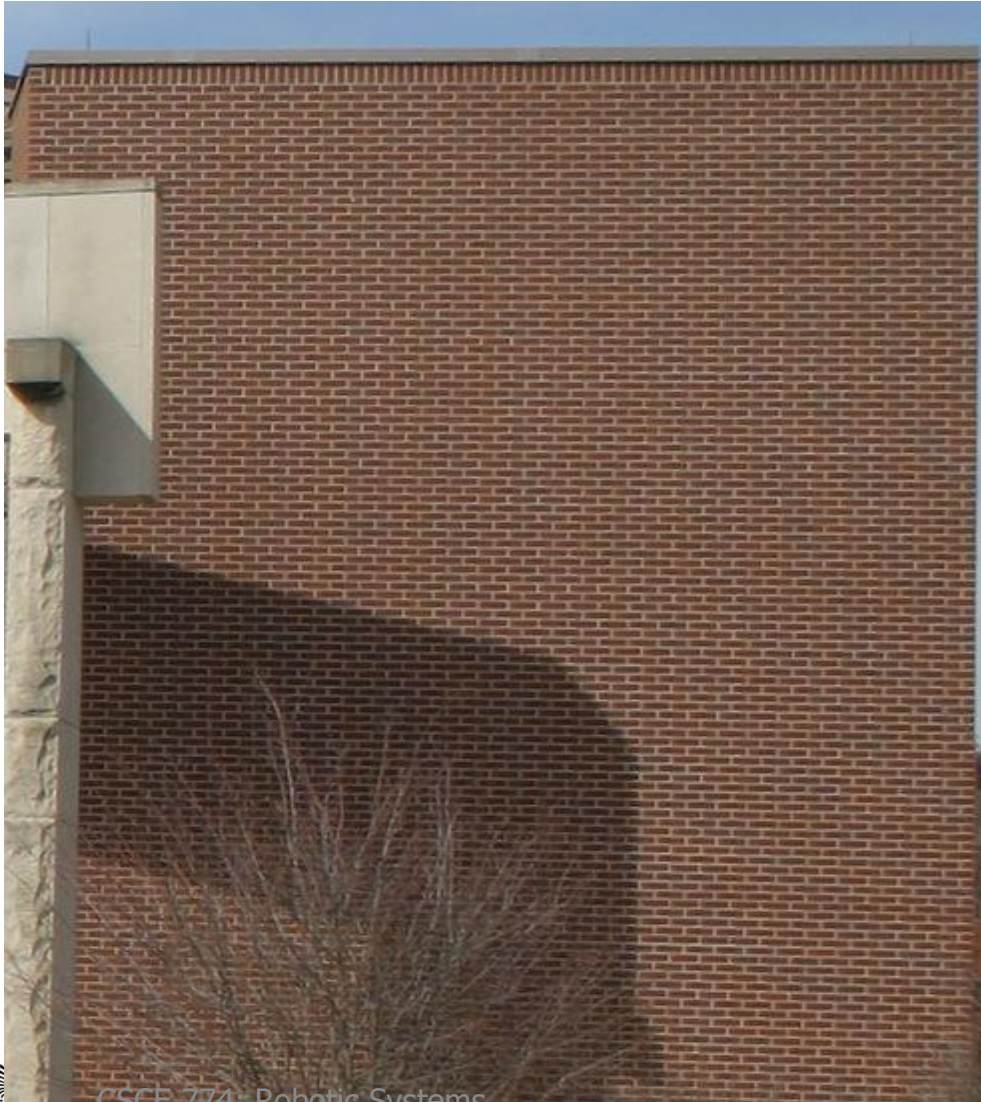
Aliasing.



- To avoid: $f_{sampling} > 2F_{max}$
 - Nyquist Rate



Aliasing: Moiré Patterns



Key problems

- Recognition:
 - What is that thing in the picture?
 - What are all the things in the image?
- Scene interpretation
 - Describe the image?
- Scene “reconstruction”:
 - What is the 3-dimensional layout of the scene?
 - What are the physical parameters that gave rise to the image?
 - What is a description of the scene?

Notion of an “inverse problem.”

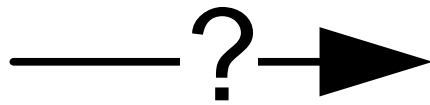
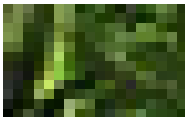


Correspondence Problem



Correspondence

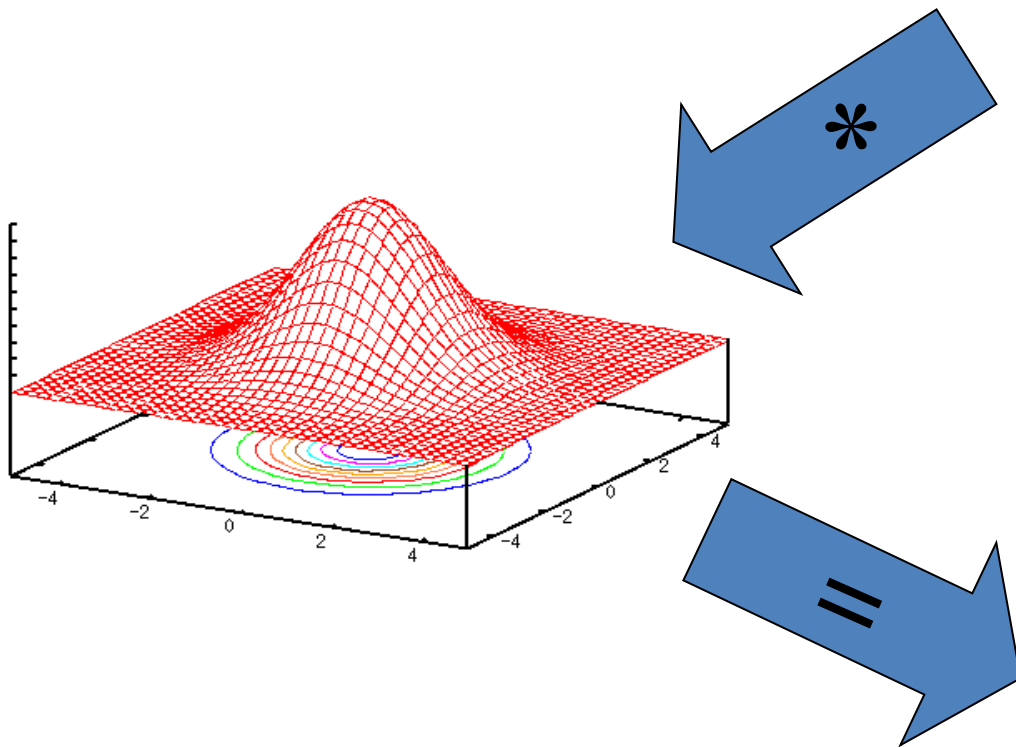
From I_1



From I_2



Gaussian Blur



Gaussian Blur and Noise

$\sigma = 4.0$ pix



$\sigma = 8.0$ pix



$\sigma = 12.0$ pix



$\sigma = 4.0$ pix



$\sigma = 8.0$ pix



$\sigma = 12.0$ pix



Gaussian Blur and Noise

$\sigma = 4.0$ pix



$\sigma = 8.0$ pix



$\sigma = 12.0$ pix



$\sigma = 4.0$ pix



$\sigma = 8.0$ pix



$\sigma = 12.0$ pix



Gaussian Blur, Noise, Sobel

$\sigma = 0.0$ pix



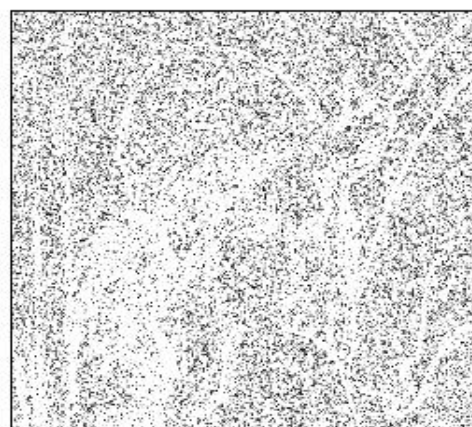
$\sigma = 4.0$ pix



$\sigma = 8.0$ pix



$\sigma = 0.0$ pix



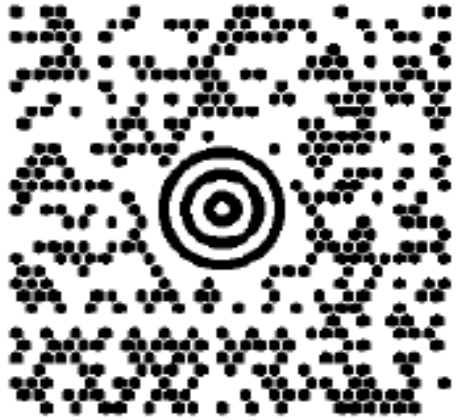
$\sigma = 4.0$ pix



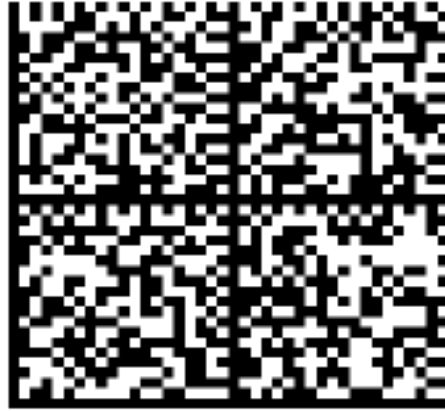
$\sigma = 8.0$ pix



Fiduciary Markers/Fiducial



(a) MaxiCode



(b) DataMatrixSymbol



(c) ARToolkit

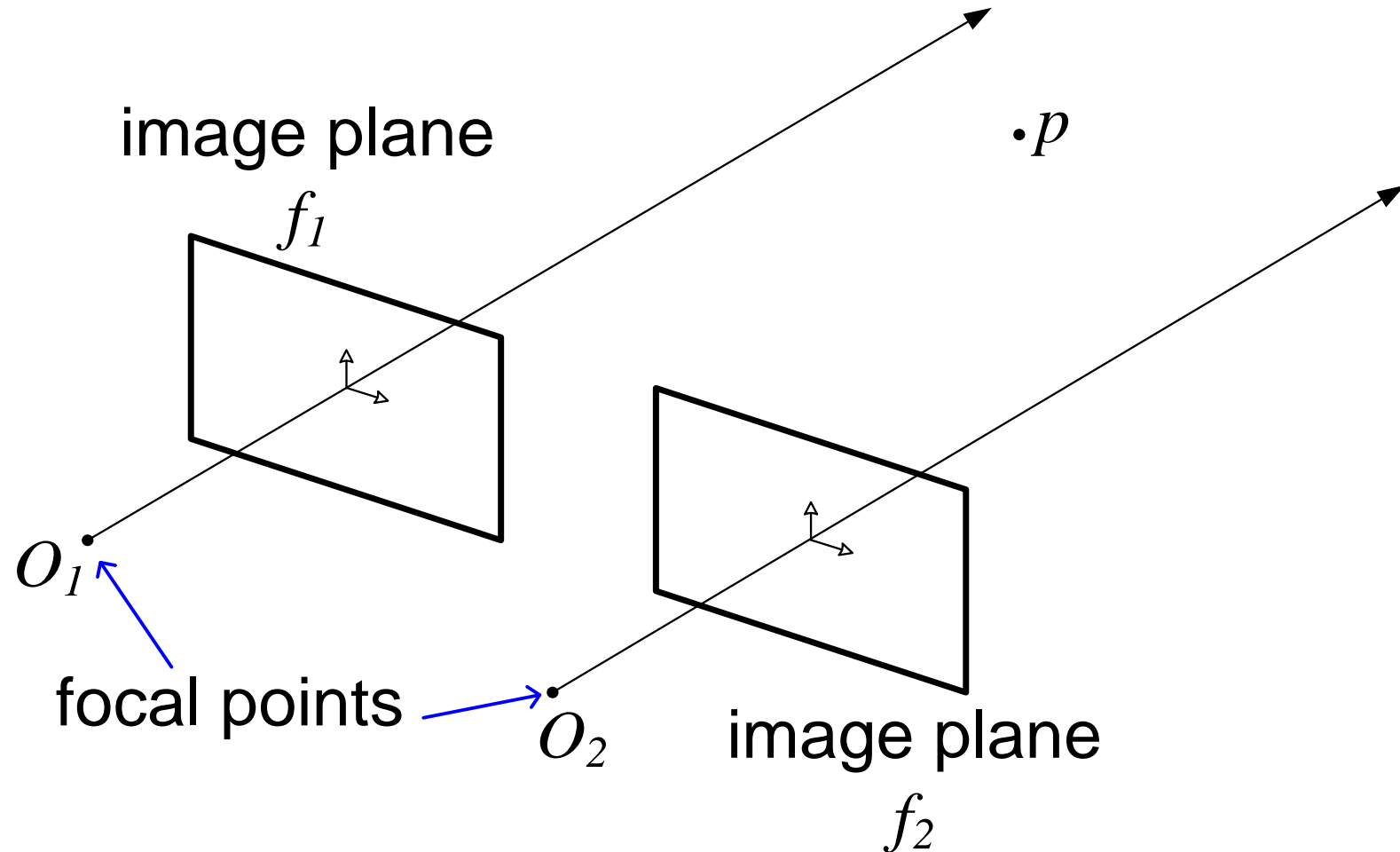


(d) ARTag

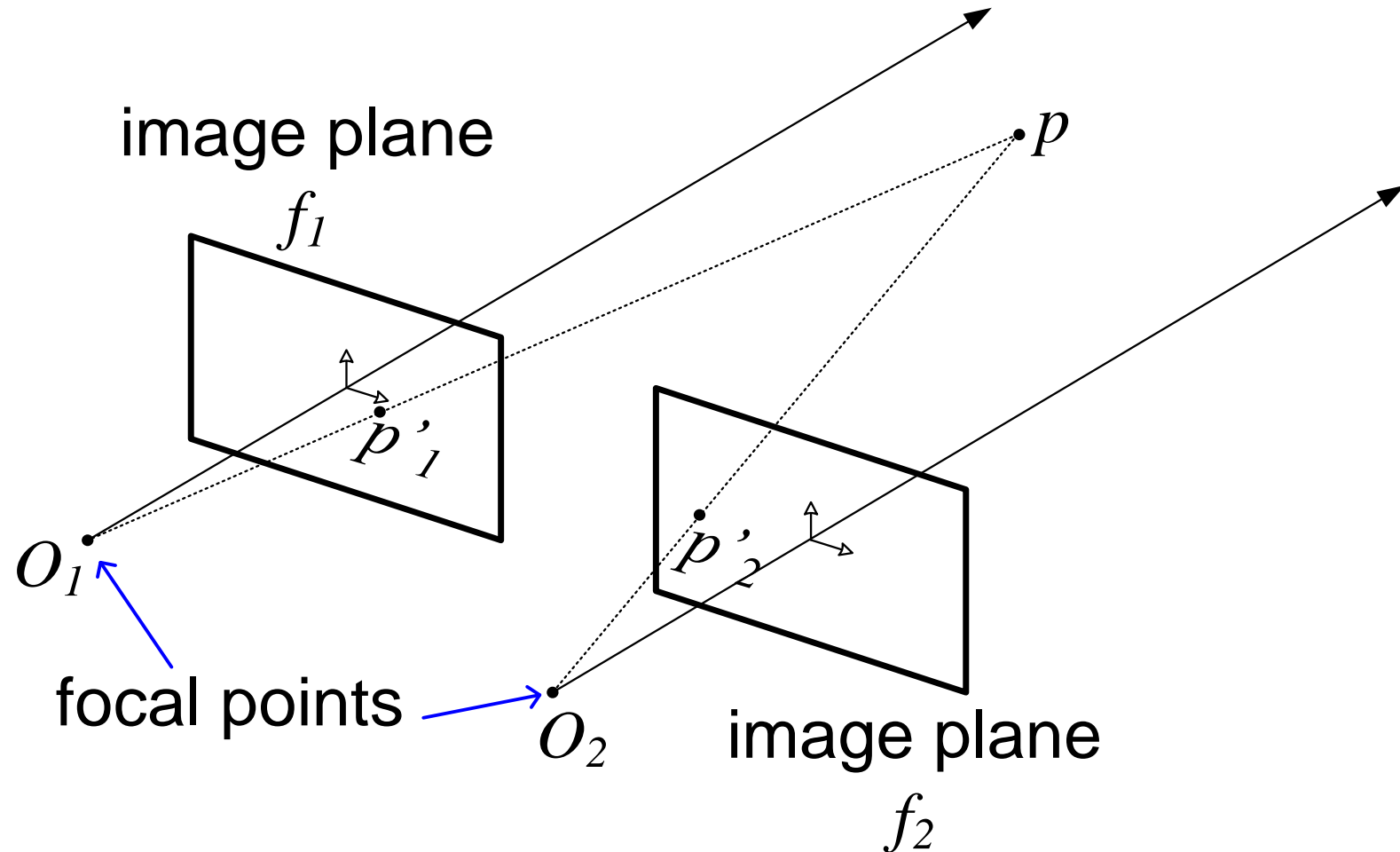


Fourier Tag

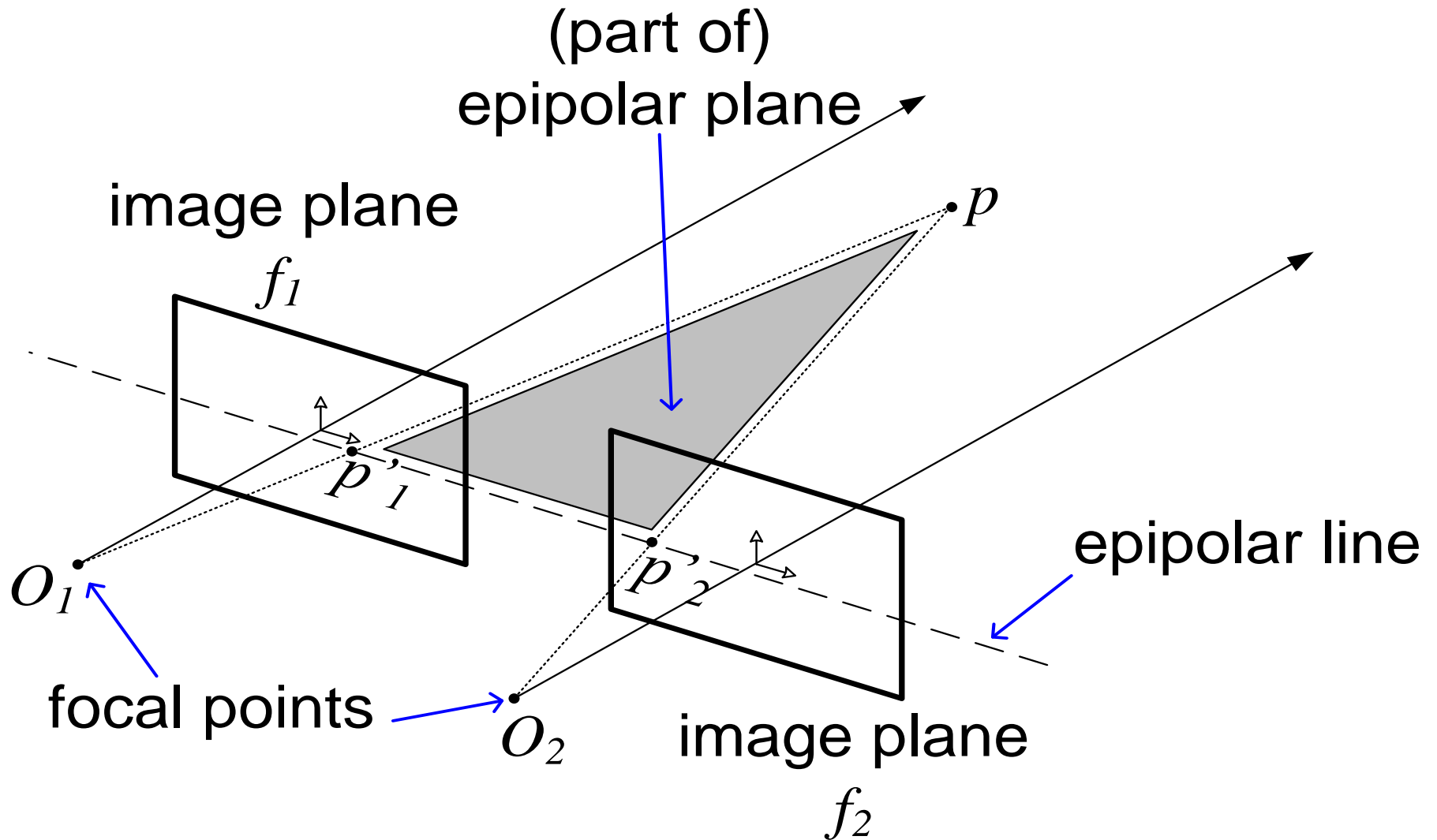
Stereo Vision: Pinhole Camera



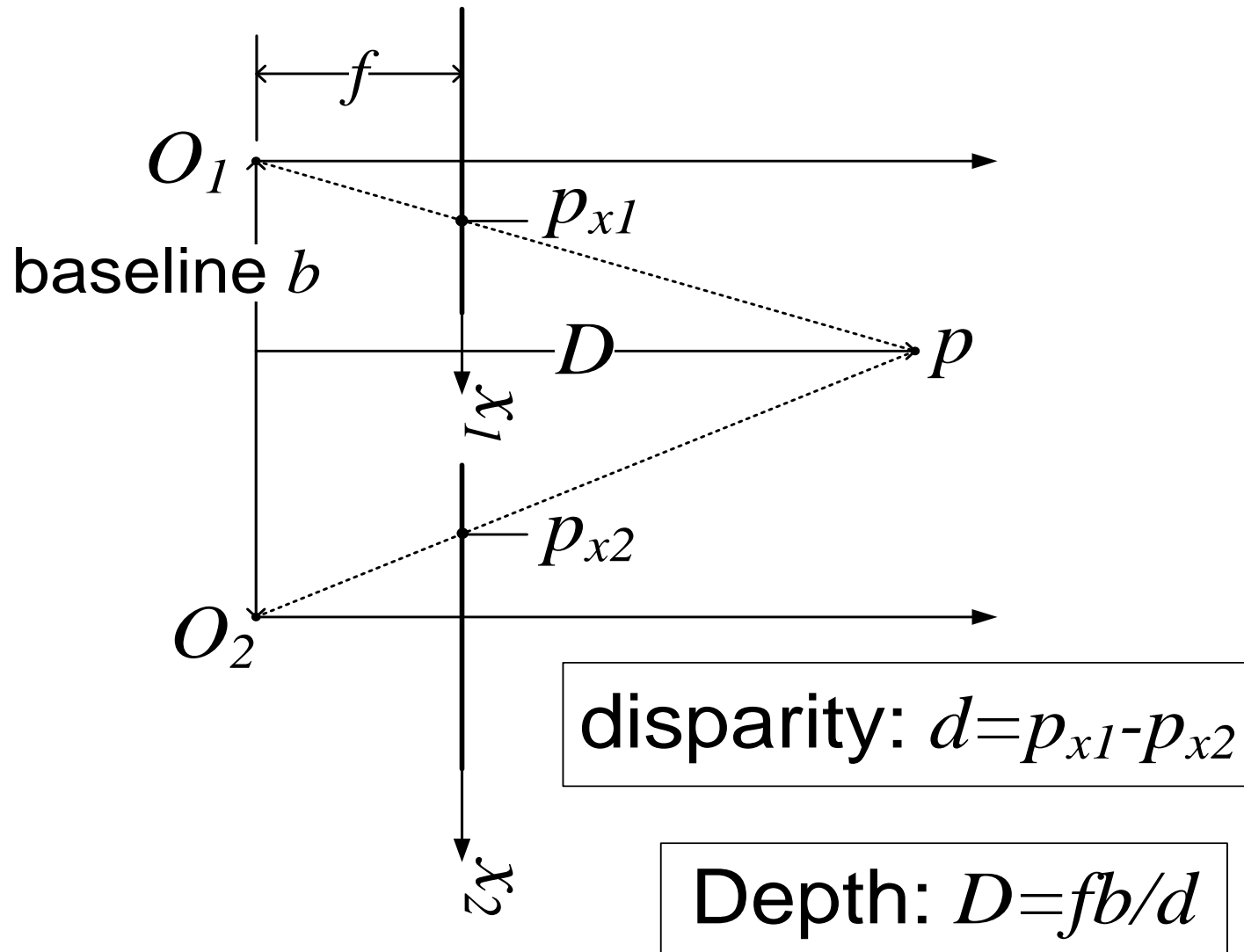
Stereo Vision: Pinhole Camera



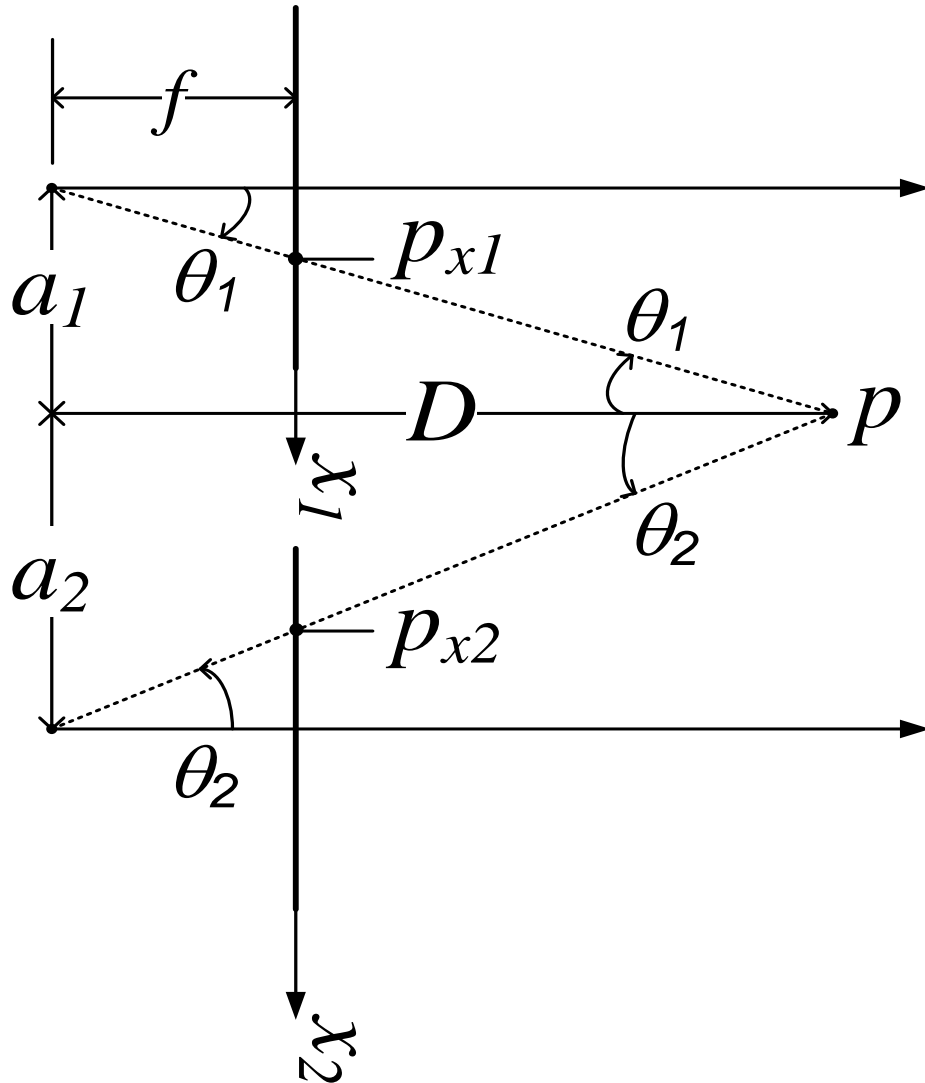
Stereo Vision: Pinhole Camera



Stereo Vision: Pinhole



Stereo Vision: Pinhole



$$\frac{p_{x1}}{f} = \frac{a_1}{D}$$

$$\frac{p_{x2}}{f} = \frac{a_2}{D}$$

$$a_1 + a_2 = b$$



Large Baseline



Stereo: Disparity Map



Using real-time stereo vision for mobile robot navigation

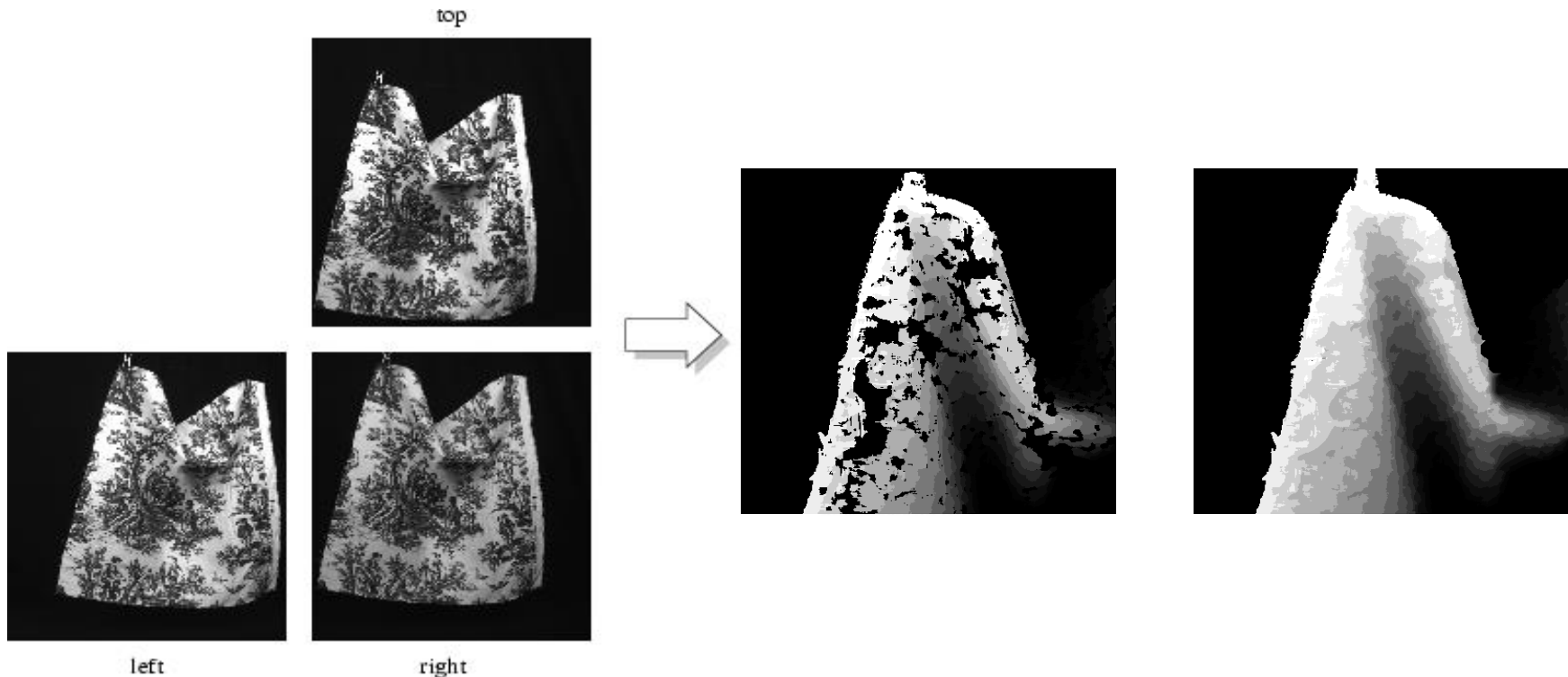
Don Murray

Jim Little

Computer Science Dept.
University of British Columbia
Vancouver, BC, Canada V6T 1Z4



Another Example (Hole Filling)

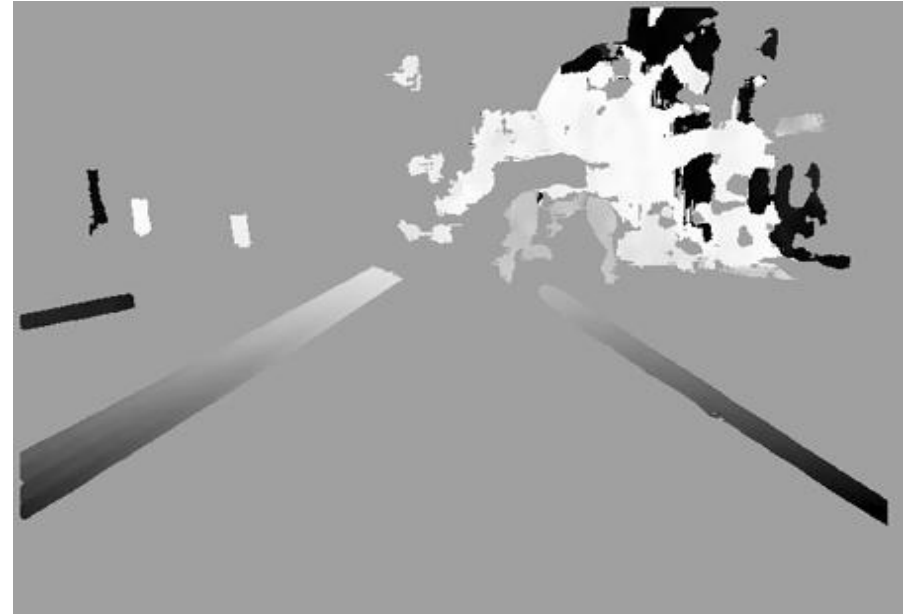


Cloth Parameters and Motion Capture by David Pritchard

B.A.Sc., University of Waterloo, 2001



Depth Map in a City



Stereo Vision

- Large number of algorithms out there:

<http://vision.middlebury.edu/stereo/>

rank 43 different algorithms.

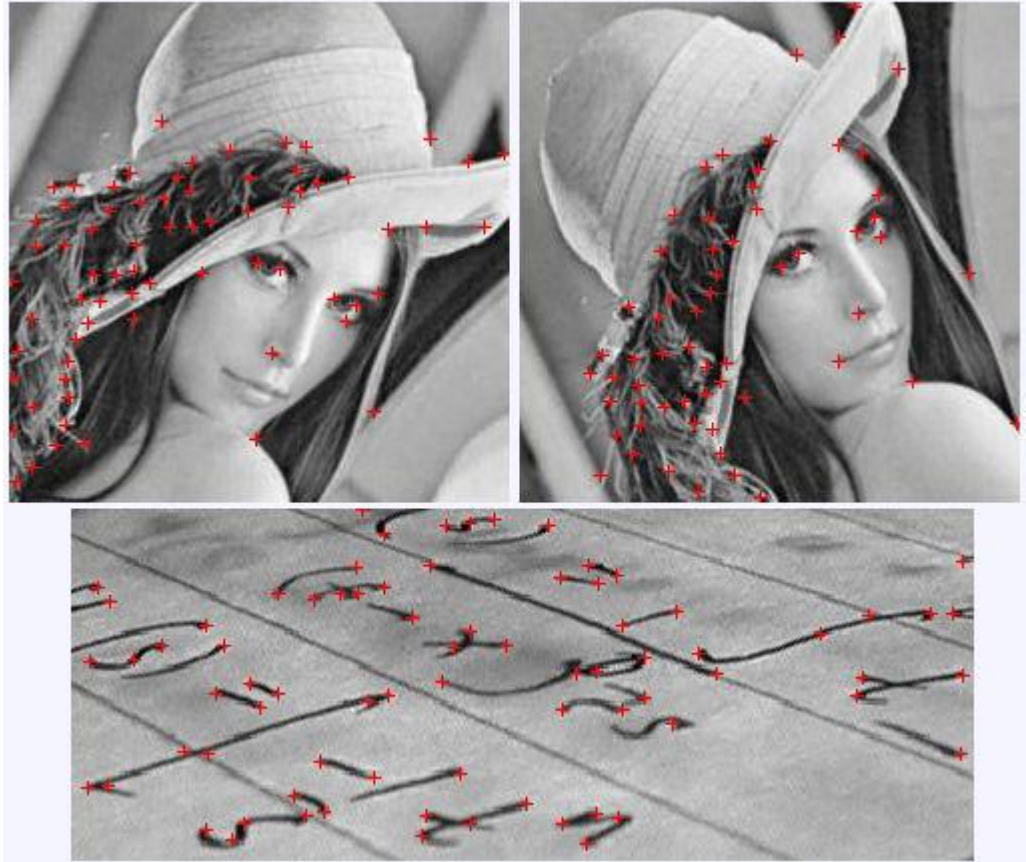
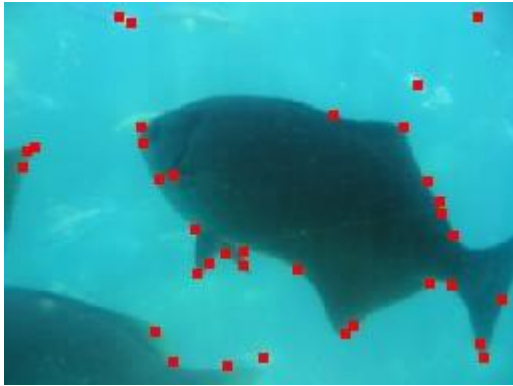


Good Feature

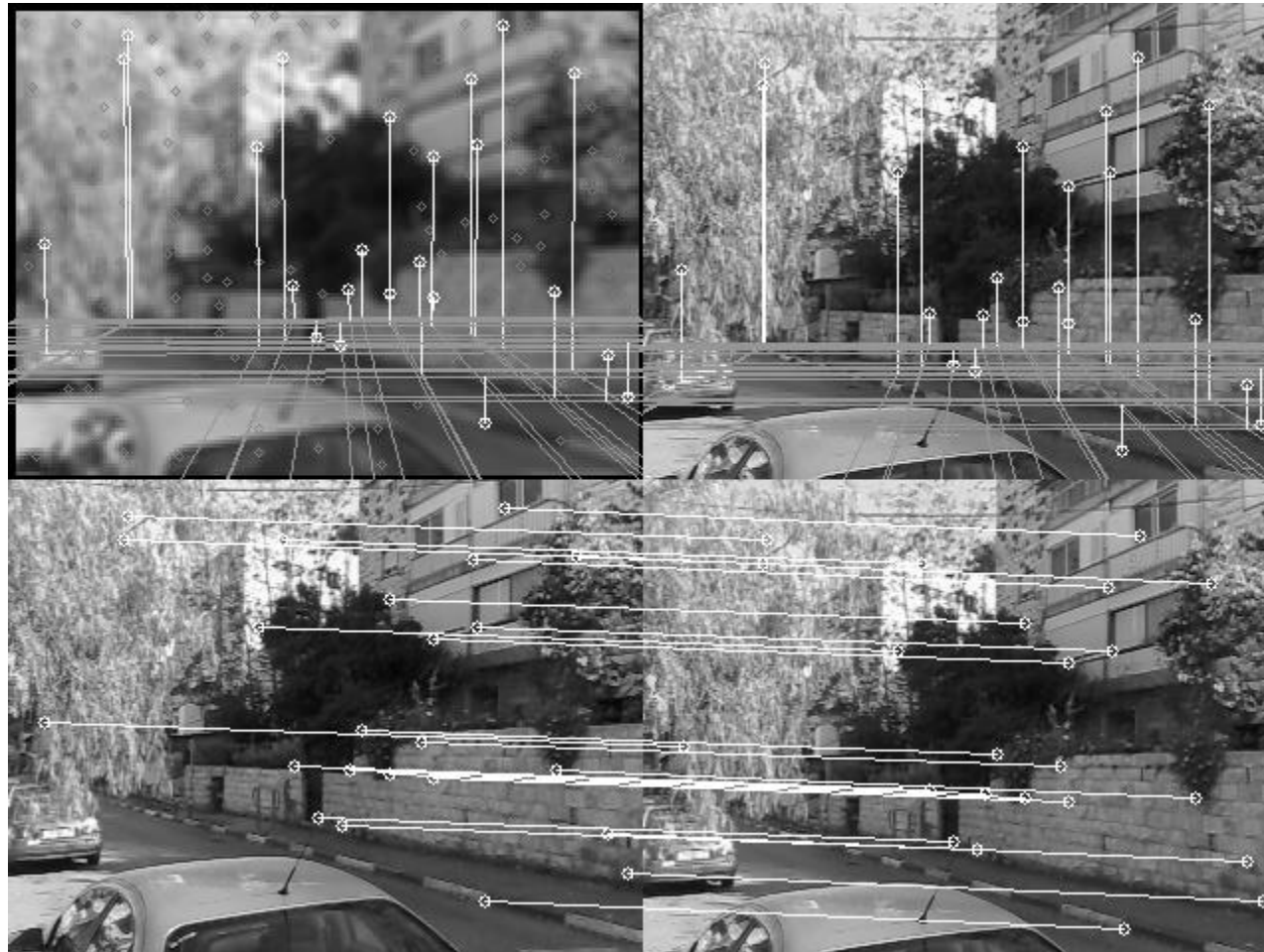
- High Recall
- Good Precision
- Feature Detection
- Feature Matching
- Several Alternatives:
 - Harris Corners (OpenCV)
 - SURF (OpenCV)
 - SIFT
 - etc



Harris Corners



SURF



SIFT

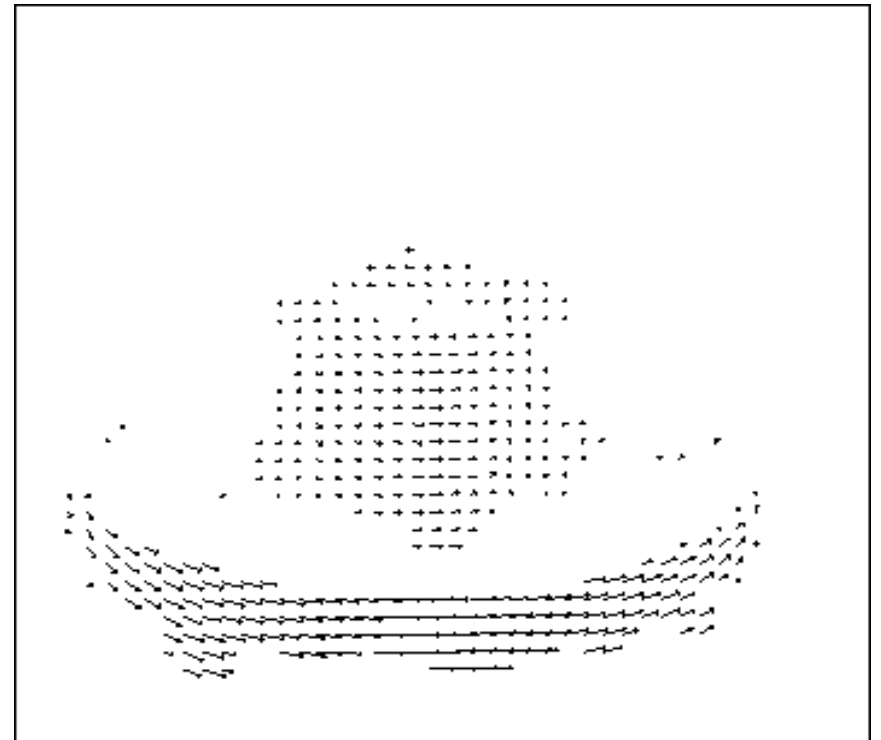
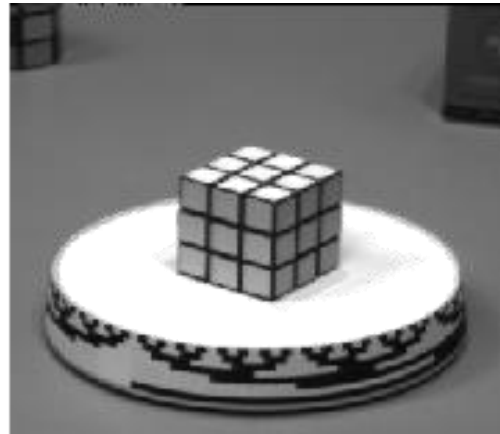
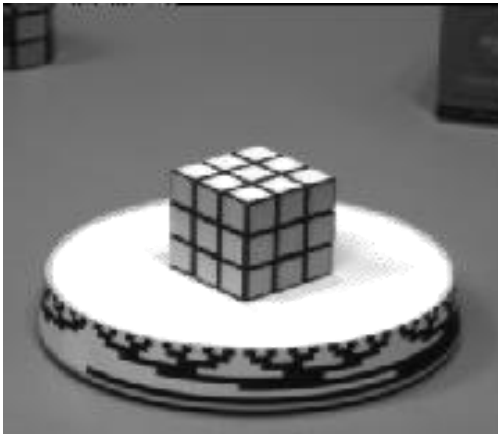


Optical Flow

- Definition:
 - *the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer (an eye or a camera) and the scene.*



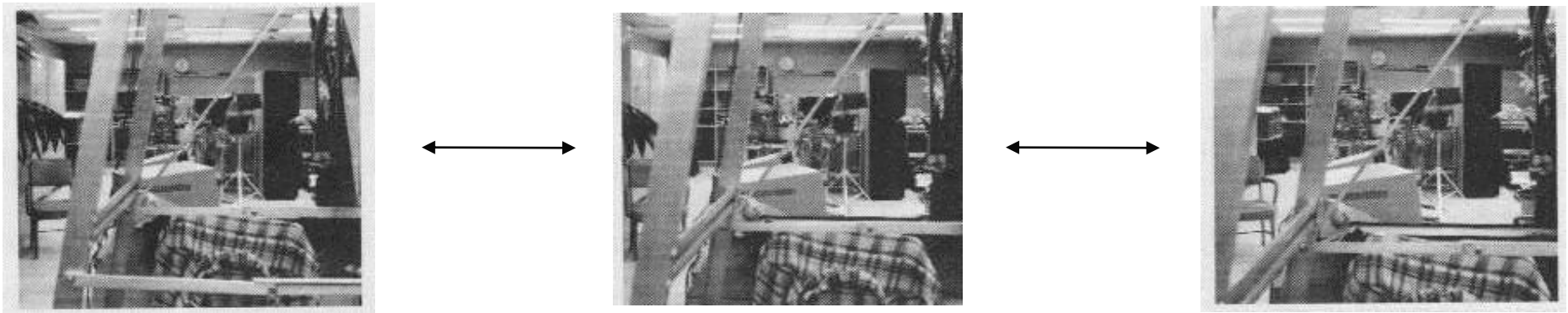
Optical Flow Field



Optical flow

Information about *image motion* rather than the *scene*.
*This is a classic **reconstruction** problem.*

This next step might be to use the image motion to infer scene motion, robot motion or 3D layout.

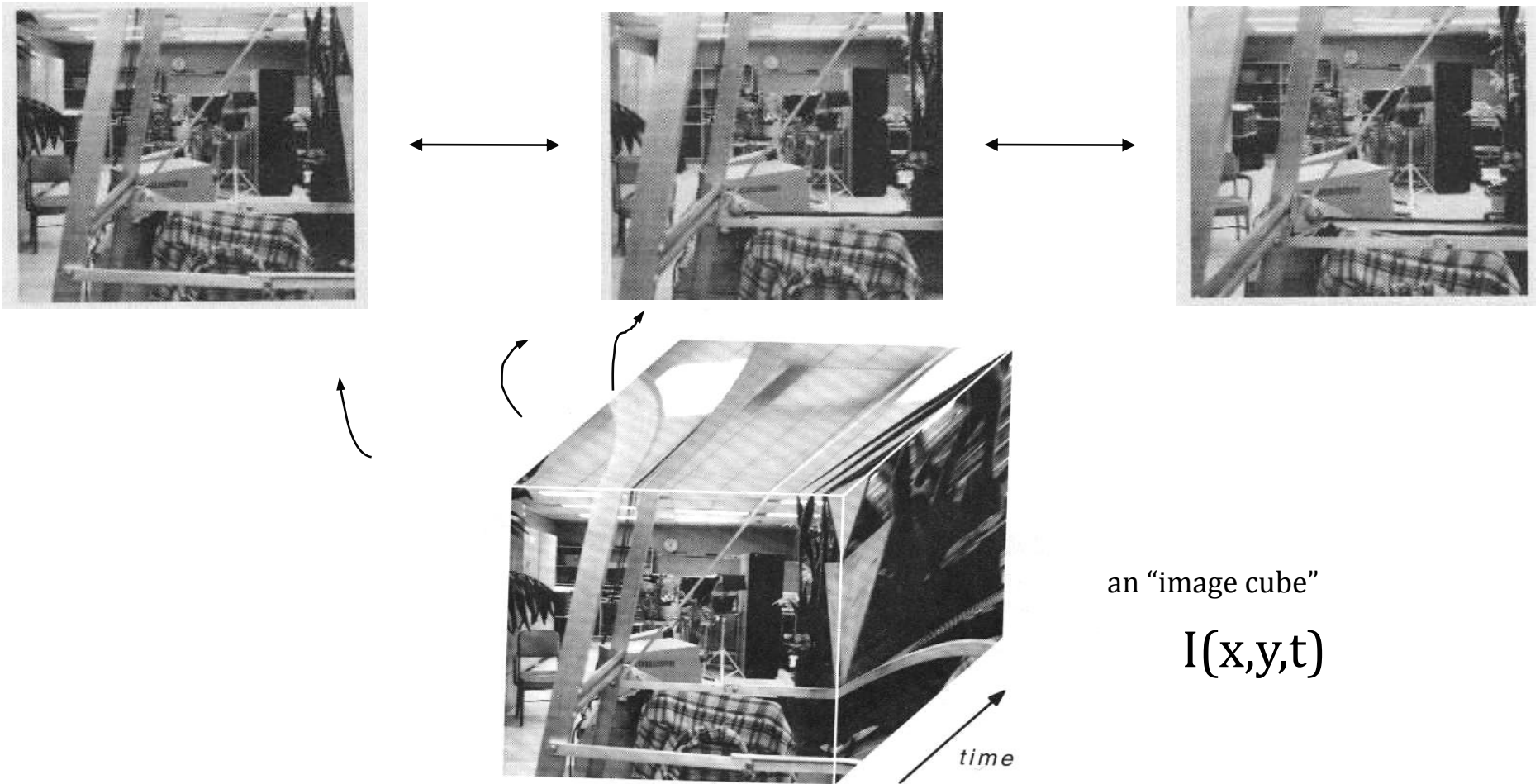


time sequence of images



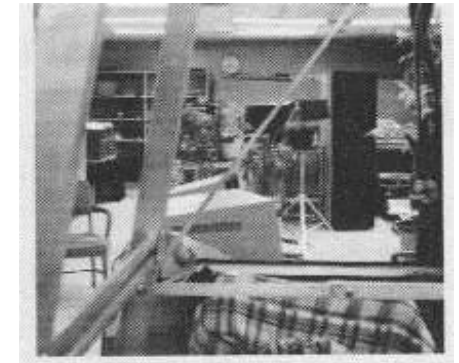
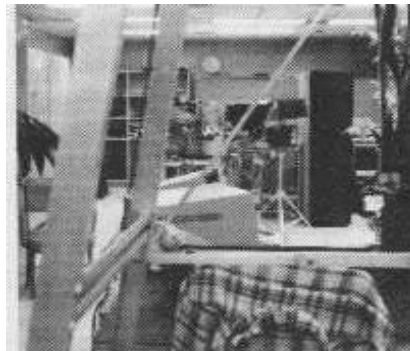
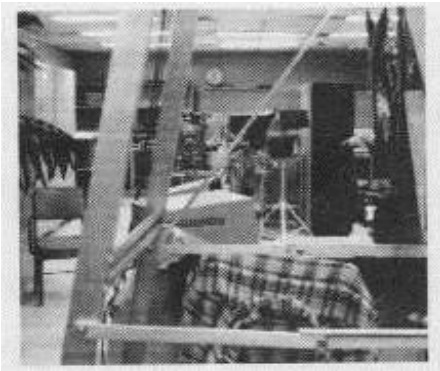
Optical flow

Information about *scene motion* rather than the *scene*.



Optical flow

Information about *scene motion* rather than the *scene*.



optical flow

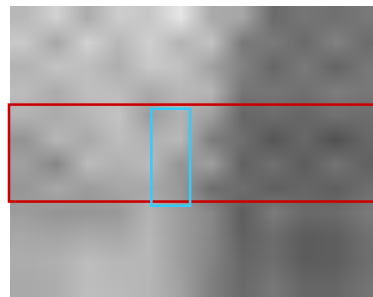
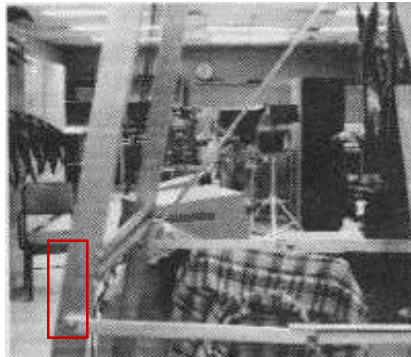
How ?



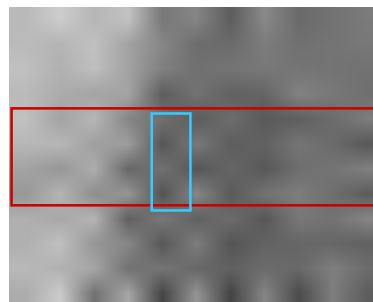
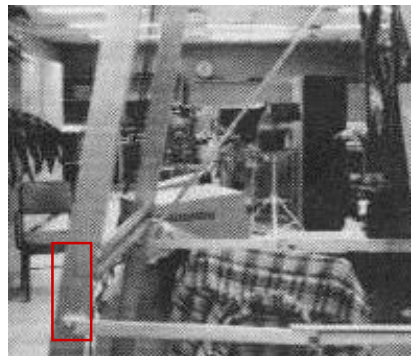
Optical Flow

- By measuring the direction that intensities are moving...

$I(x,y,t)$



99	90	90	70	40
95	90	70	40	40
90	90	70	40	40
90	90	70	40	40
90	70	50	40	30



90	90	70	40	25
90	70	40	40	25
90	70	40	40	25
90	70	40	40	20
70	50	40	30	15

- We can estimate things...



Observations & Warnings

- How can we do this?
- Assume the scene itself is static.
- Find matching chunks in the images.
- An instance of *correspondence*.

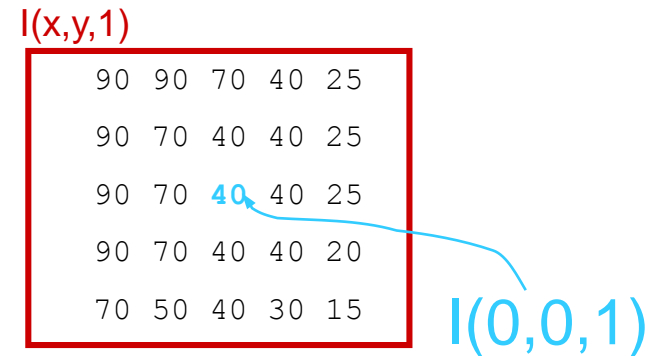
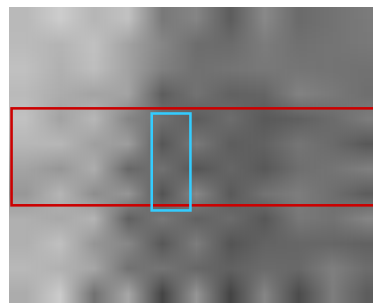
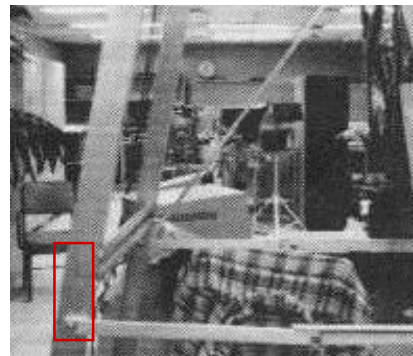
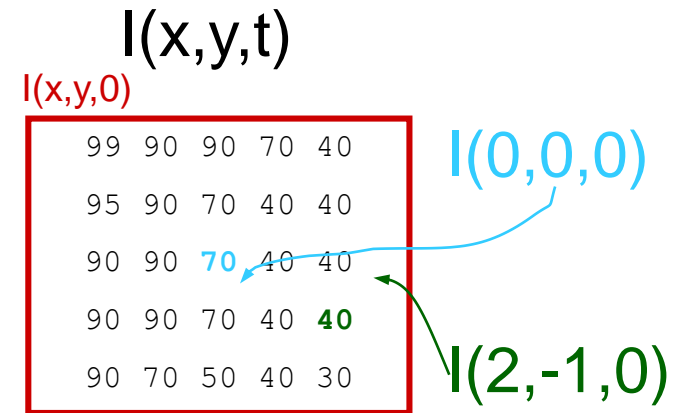
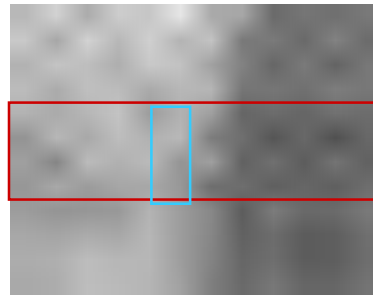
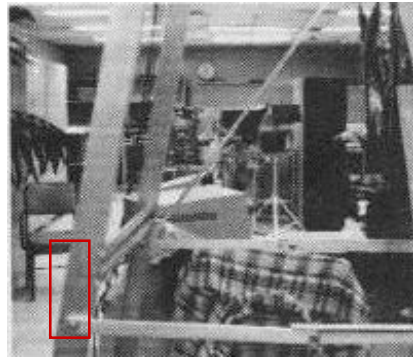
BUT

- World really isn't static.
- Lightning might change even in a static scene.



Optical Flow

By measuring the direction that intensities are moving...



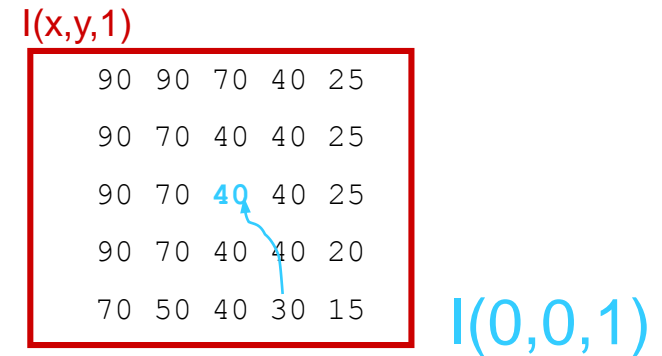
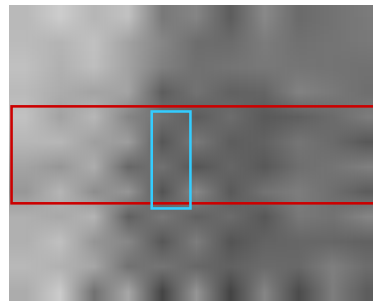
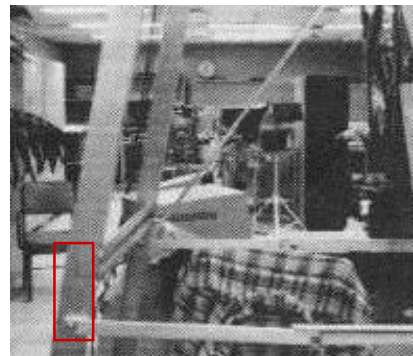
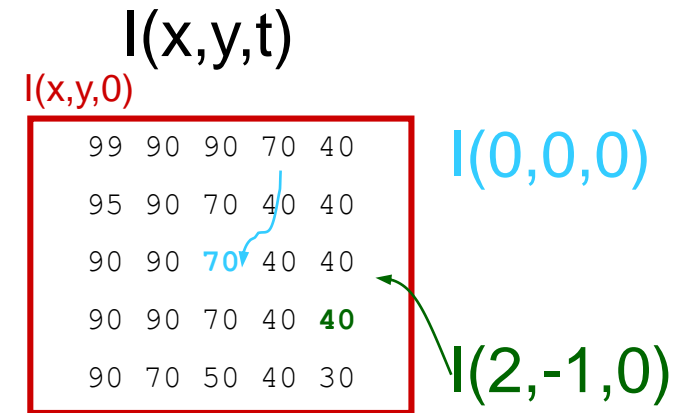
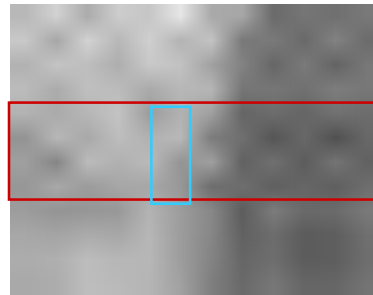
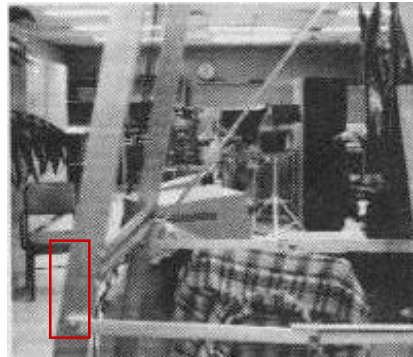
We can estimate things ...

$$\frac{dI}{dx} = I_x \text{ at } (0,0,0)$$



Optical Flow

By measuring the direction that intensities are moving...



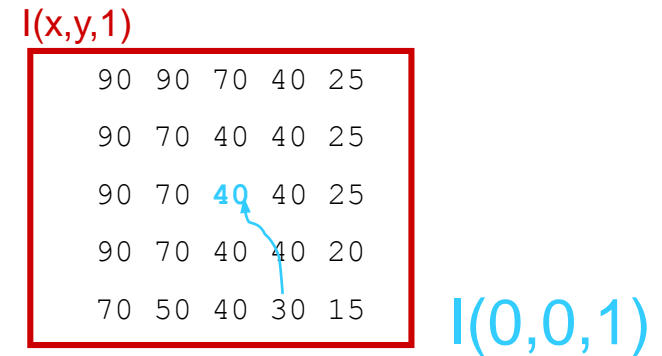
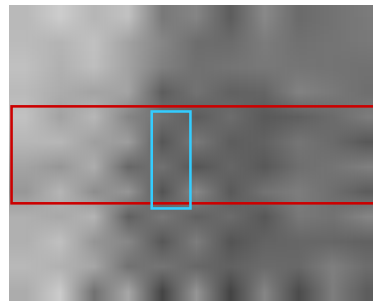
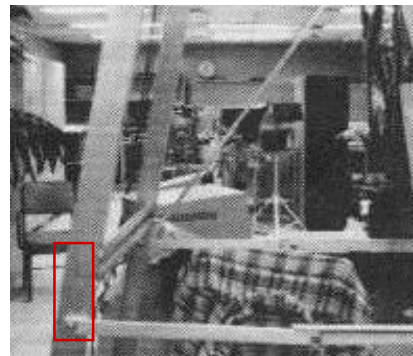
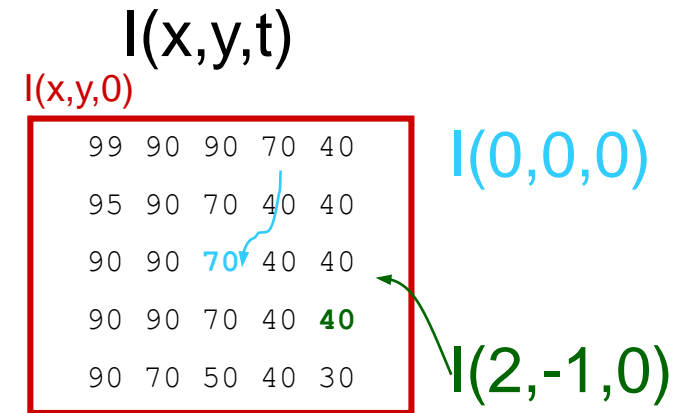
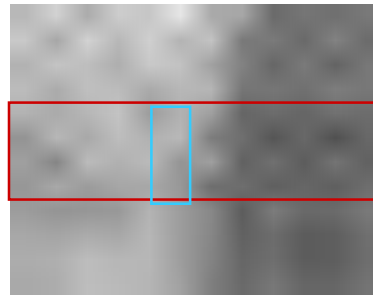
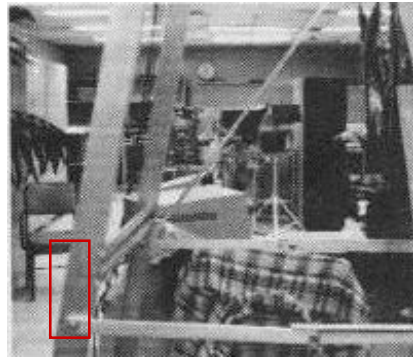
We can estimate things like

$$\frac{dI}{dx} = I_x \text{ at } (0,0,0) = \frac{\Delta I}{\Delta x} = \frac{I(1,0,0) - I(0,0,0)}{1 - 0} = -30$$



Optical Flow

By measuring the direction that intensities are moving...



We can estimate things like

$$\frac{dI}{dx} = I_x$$

$$\frac{dI}{dy} = I_y$$

$$\frac{dI}{dt} = I_t$$

SO...




Measuring Optical Flow

Let $I(x,y,t)$ be the sequence of images.

Simplest assumption (constant brightness constraint):

$$I(x,y,t) = I(x + dx, y + dy, t + dt)$$

(x,y,t)



99	90	90	70	40
95	90	70	40	40
90	90	70	40	40
90	90	70	40	40
90	70	50	40	30




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90	90	70	40	40
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Reminder: $f(x + dx) = f(x) + f'(x) dx + f''(x) dx^2 / 2 + \dots$




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$$I(x,y,t) = I(x,y,t) + I_x dx + I_y dy + I_t dt + \text{2nd deriv.} + \text{higher}$$



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$$I(x,y,t) = I(x,y,t) + I_x dx + I_y dy + I_t dt + \text{2nd deriv. + higher}$$

$$0 = I_x dx + I_y dy + I_t dt$$

ignore these terms



Measuring Optical Flow

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(x,y,t)

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95	90	70	40	40
90	90	70	40	40
90	90	70	40	40
90	70	50	40	30

Reminder: $f(x + dx) = f(x) + f'(x) dx + f''(x) dx^2 / 2 + \dots$

$$I(x,y,t) = I(x,y,t) + I_x dx + I_y dy + I_t dt + \text{2nd deriv. + higher}$$

$$0 = I_x dx + I_y dy + I_t dt$$

ignore these terms

$$-I_t = I_x \frac{dx}{dt} + I_y \frac{dy}{dt}$$

intensity-flow equation

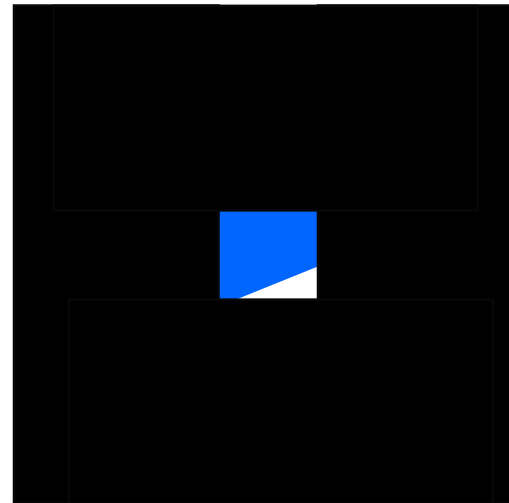
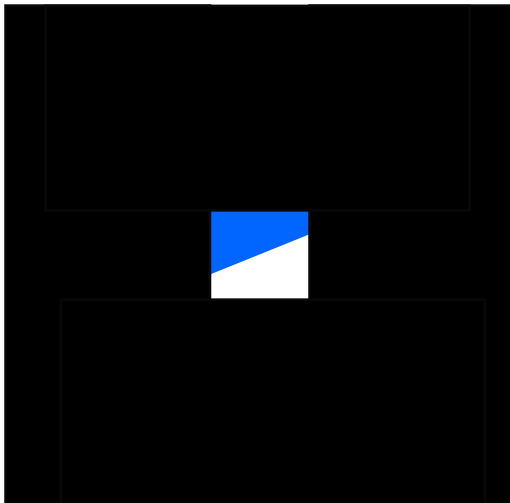
good and bad...



The “aperture” problem

$$-I_t = I_x \frac{dx}{dt} + I_y \frac{dy}{dt}$$

- The intensity-flow equation provides only one constraint on *two* variables (x-motion and y-motion)
- It is only possible to find optical flow in one direction...



The “aperture” problem

- It is only possible to find optical flow in one direction...
*at any **single** point in the image !*



Smoothing can be done by incorporating neighboring points' information.

Optical Flow Application

- Visual Odometry
 - Wheel slip detection on future Mars Rovers



Image Downsampling

