UNIVERSITY OF
SOUTH CAROLINA

CSCE 574 ROBOTICS

Computer Vision

Slides curtesy of Professor Gregory Dudek

Ioannis Rekleitis

Why vision?

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

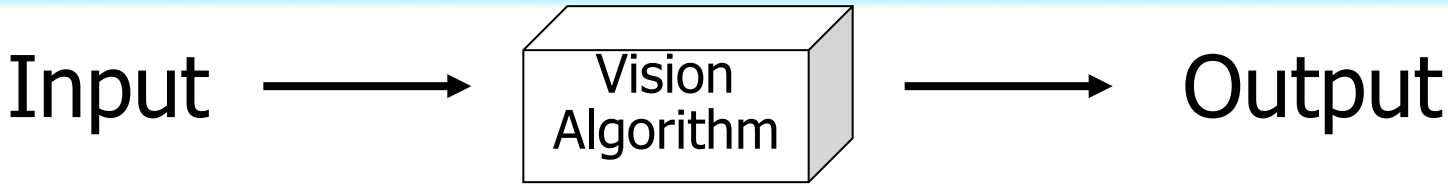
So, what's the problem?

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

Problems:

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

The "Vision Problem"



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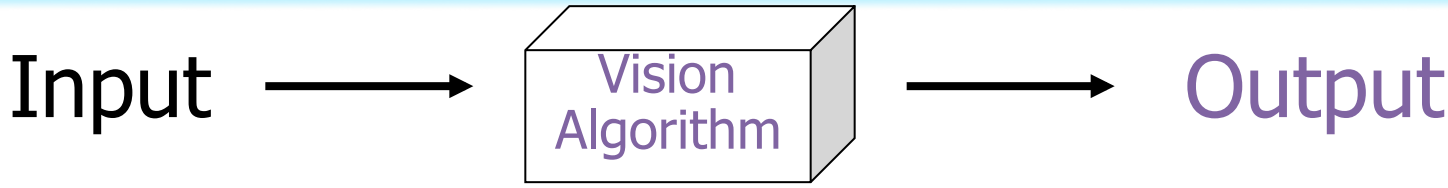

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253 250 170 242 253 138 199 193 216 146 255 253 253 253 233
254 228 164 209 235 144 188 144 161 192 230 250 253 255 252
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253 230 167 207 217 113 106 069 168 098 244 246 239 207 254
253 219 170 225 253 122 144 169 124 109 243 235 233 252 252
255 221 179 239 227 123 123 069 125 122 240 249 243 232 253
221 217 180 213 243 126 143 081 181 133 252 249 244 221 210
236 216 178 208 230 225 160 118 187 198 249 249 230 220 221
229 224 183 217 216 165 209 133 193 209 222 238 236 220 214
230 223 185 240 225 212 027 187 202 239 233 234 237 225 232
221 215 189 207 220 221 003 063 209 006 204 203 232 229 216
223 217 198 162 194 215 192 106 077 255 213 219 194 215 219
224 216 162 189 200 254 217 198 209 216 206 226 186 228 219
215 222 168 202 214 201 117 084 085 111 234 190 248 218 226
219 216 198 165 213 227 014 221 197 183 178 186 216 214 222
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200 205 135 143 100 174 027 175 189 113 121 150 190 209 184
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The "Vision Problem"

Input → Vision Algorithm → Output

207	200	194	194	203	130	105	095	107	153	192	196	190	186	175
242	194	222	254	255	124	074	082	072	076	208	206	202	194	185
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248	248	169	227	252	111	066	118	061	021	252	251	255	255	142
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254	228	169	213	235	146	123	096	090	130	230	250	253	254	254
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254	234	167	212	217	110	070	049	098	074	244	246	239	207	254
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221	217	180	213	243	109	079	048	100	045	246	249	244	221	210
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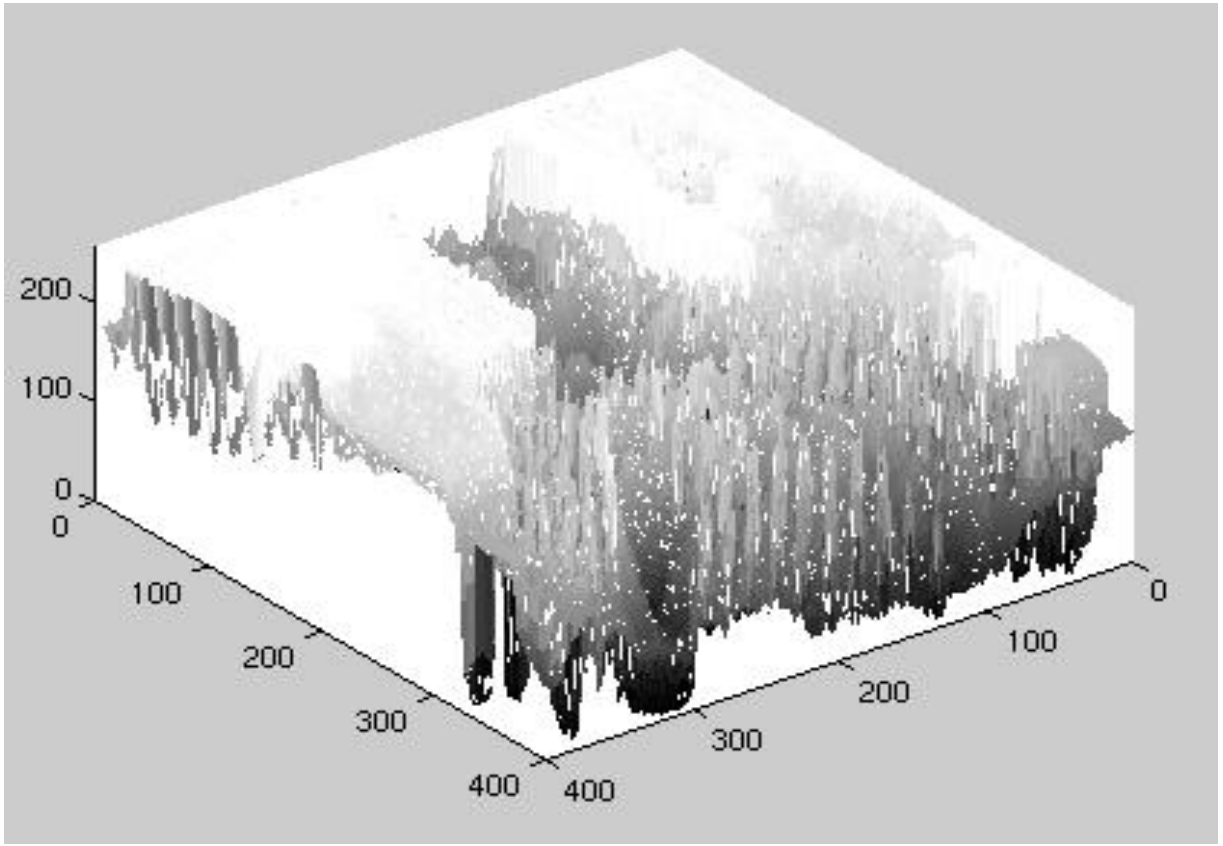

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253 254 079 072 116 089 020 068 103 074 031 130 106 052 161
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138 074 030 082 030 038 076 041 141 046 045 040 009 063 149
135 016 057 071 035 025 040 062 030 084 130 043 059 113 151

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255	197	192	255	248	133	024	027	076	032	250	255	255	181	255
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223	217	132	046	072	076	056	048	013	182	073	076	083	215	219
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184	181	066	019	043	038	046	083	057	050	145	048	035	087	158
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025 161 174 172 167 049 200 193 112 028 120 169 173 177 173

What does a robot need ?

doesn't need a full interpretation of available images

"This is Prof. X in his office offering me a cup of iced tea."

does need information about what to do...

"Run Away!!"

reactive

deliberative

- avoiding obstacles (or predators)
- pursuing objects
- localizing itself
- Mapping
- finding targets
- reasoning about the world ...

environmental interactions

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

What does a robot need ?

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

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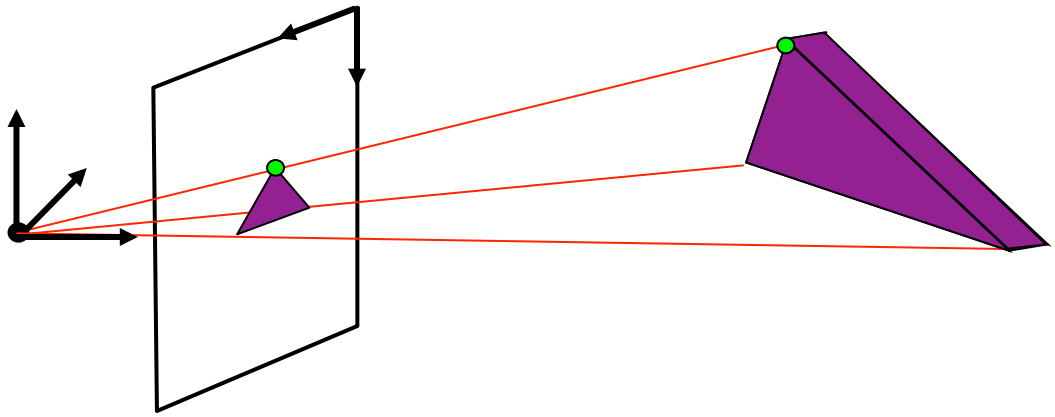
Ill-posed

- 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.

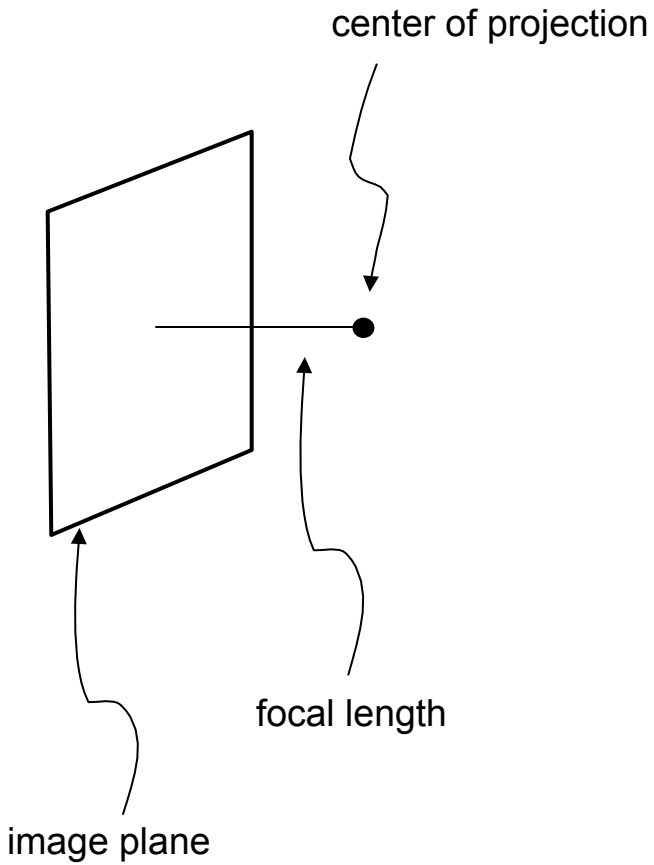
Ill-posed

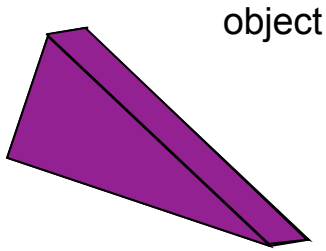
- In trying to extract 3d structure from 2d images, vision is an *ill-posed* problem.

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

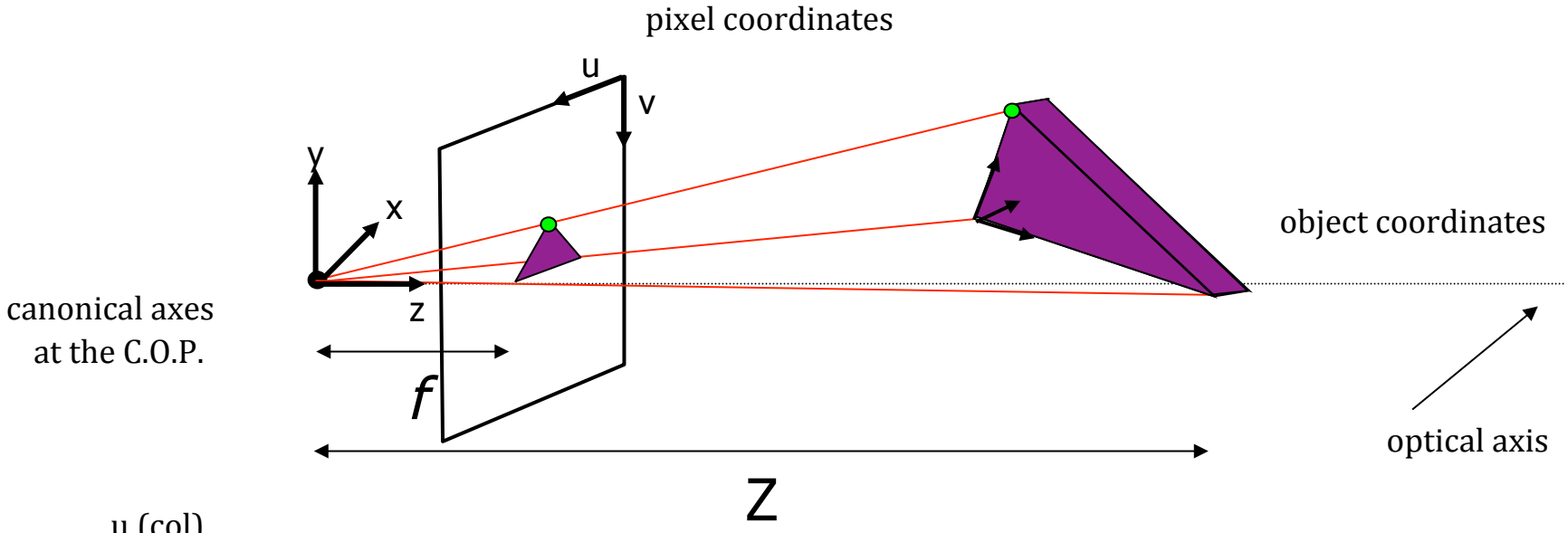
Camera Geometry

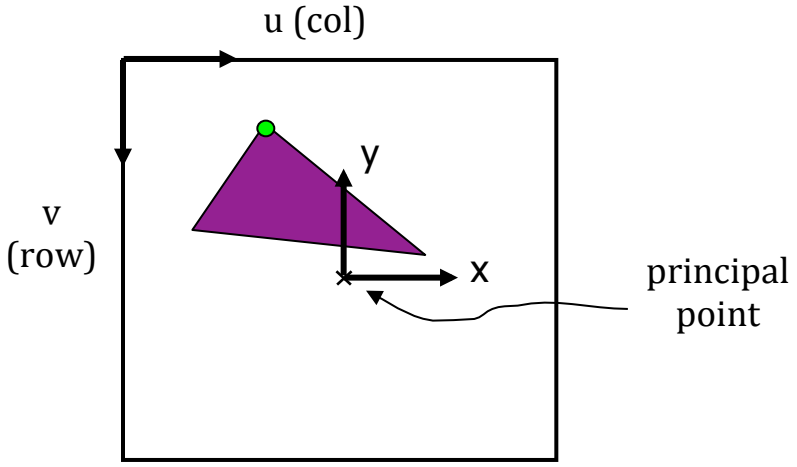
3D→2D transformation: perspective projection





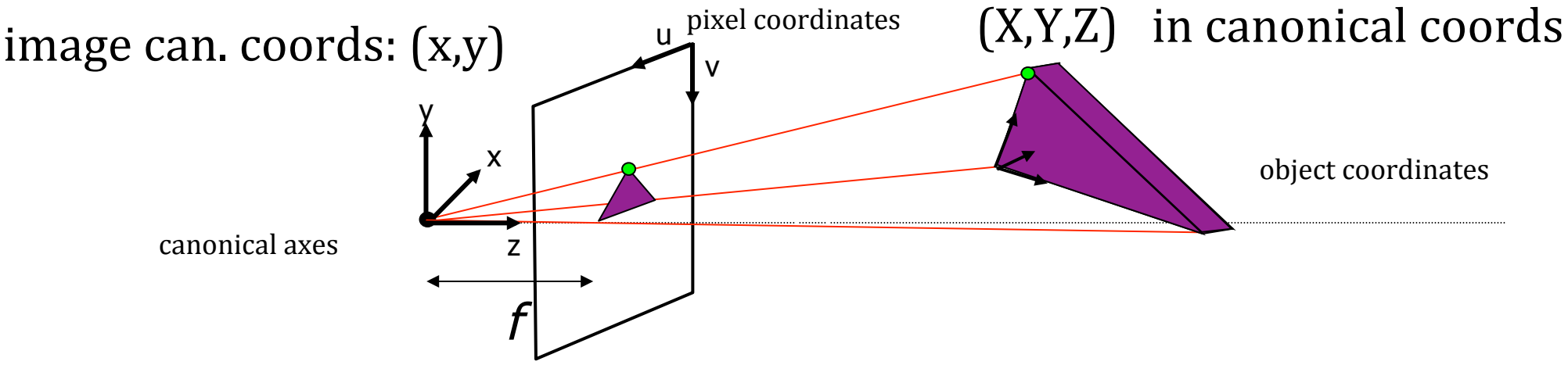
Coordinate Systems



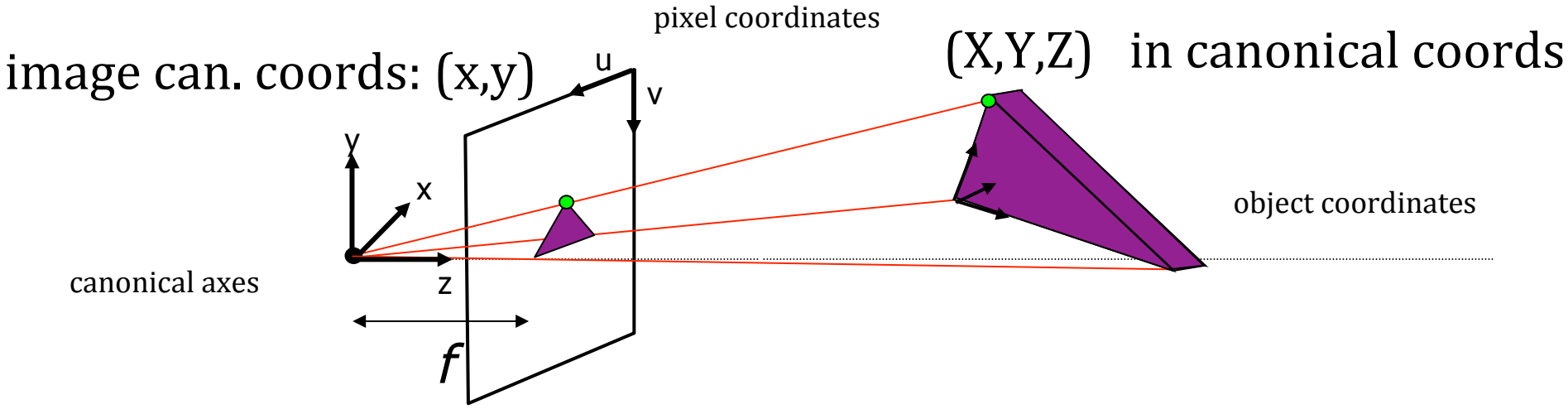


Add coordinate systems in order to describe feature points...

Coordinate Systems



From 3d to 2d



$$x = \frac{fX}{Z} \qquad y = \frac{fY}{Z}$$

a nonlinear transformation

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

Camera Calibration

- Camera Model
  - $[u\ v\ 1]$ Pixel coords
  - $\begin{bmatrix} x_w & y_w & z_w & 1 \end{bmatrix}^T$ World coords

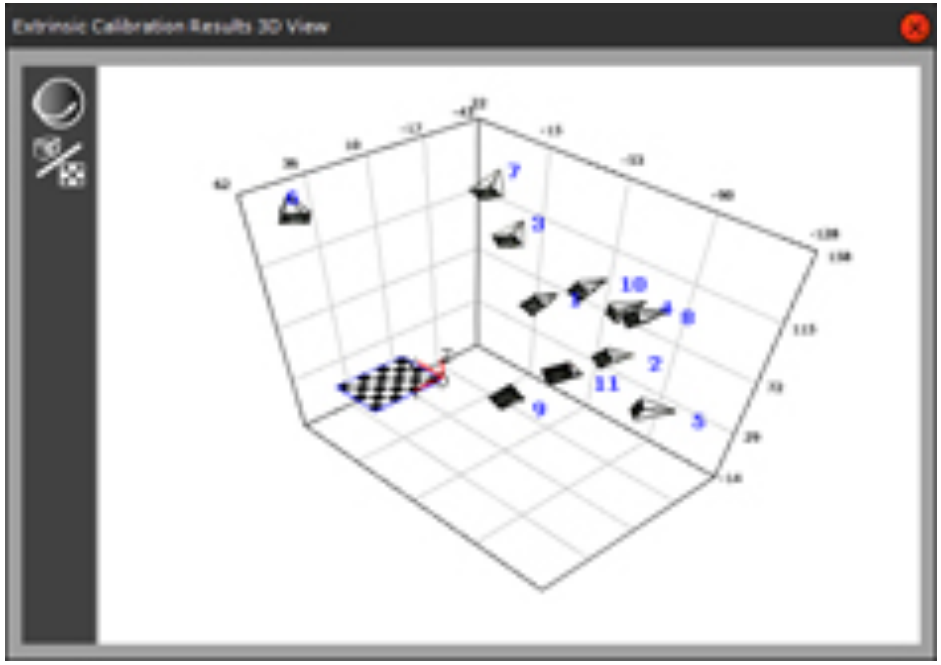
$$z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = A \begin{bmatrix} R & T \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

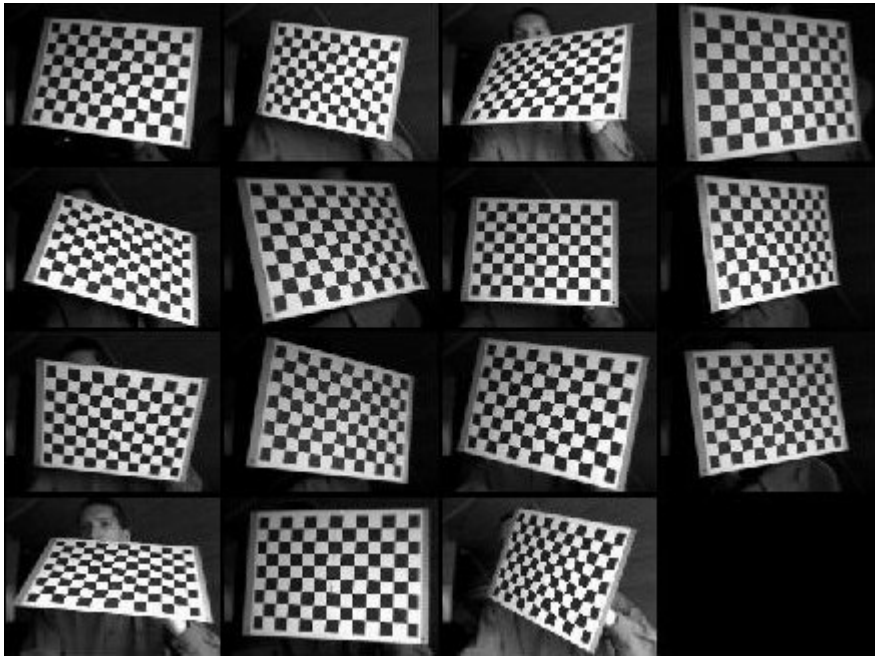
- Intrinsic Parameters
  - $\alpha_x = f \cdot m_x, \alpha_y = f \cdot m_y$ focal lengths in pixels
  - γ skew coefficient
  - u_0, v_o focal point

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

- Extrinsic Parameters
  - $\begin{bmatrix} R & T \end{bmatrix}$ Rotation and Translation

Camera Calibration





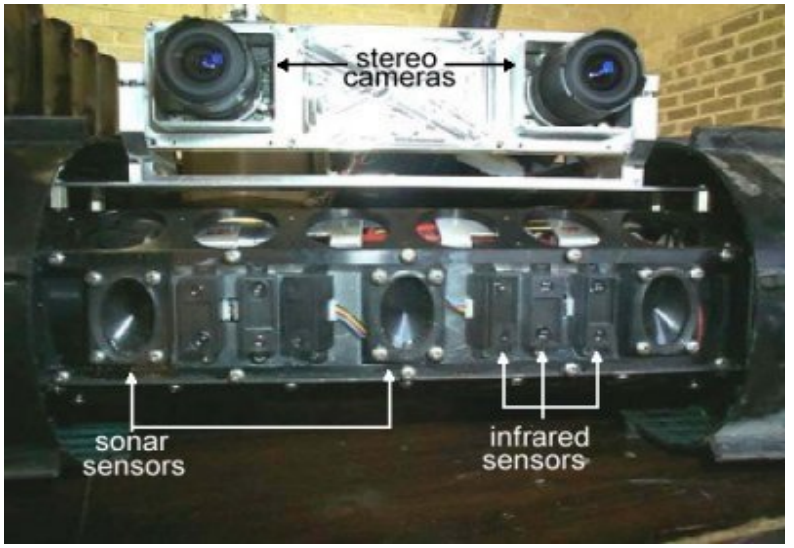
Existing packages in MATLAB, OpenCV, etc

A Vision "solution"

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

multiple times

multiple cameras



Robot vision sampler

A brief overview of robotic vision processing...

(1) Image streams → simplified via generality
(1) Image streams → simplified via specificity

(2) Stereo vision → (or beyond...)

(3) Incorporating vision within robot control
- ↓ 3d reconstruction
- ↓ Visual "servoing"

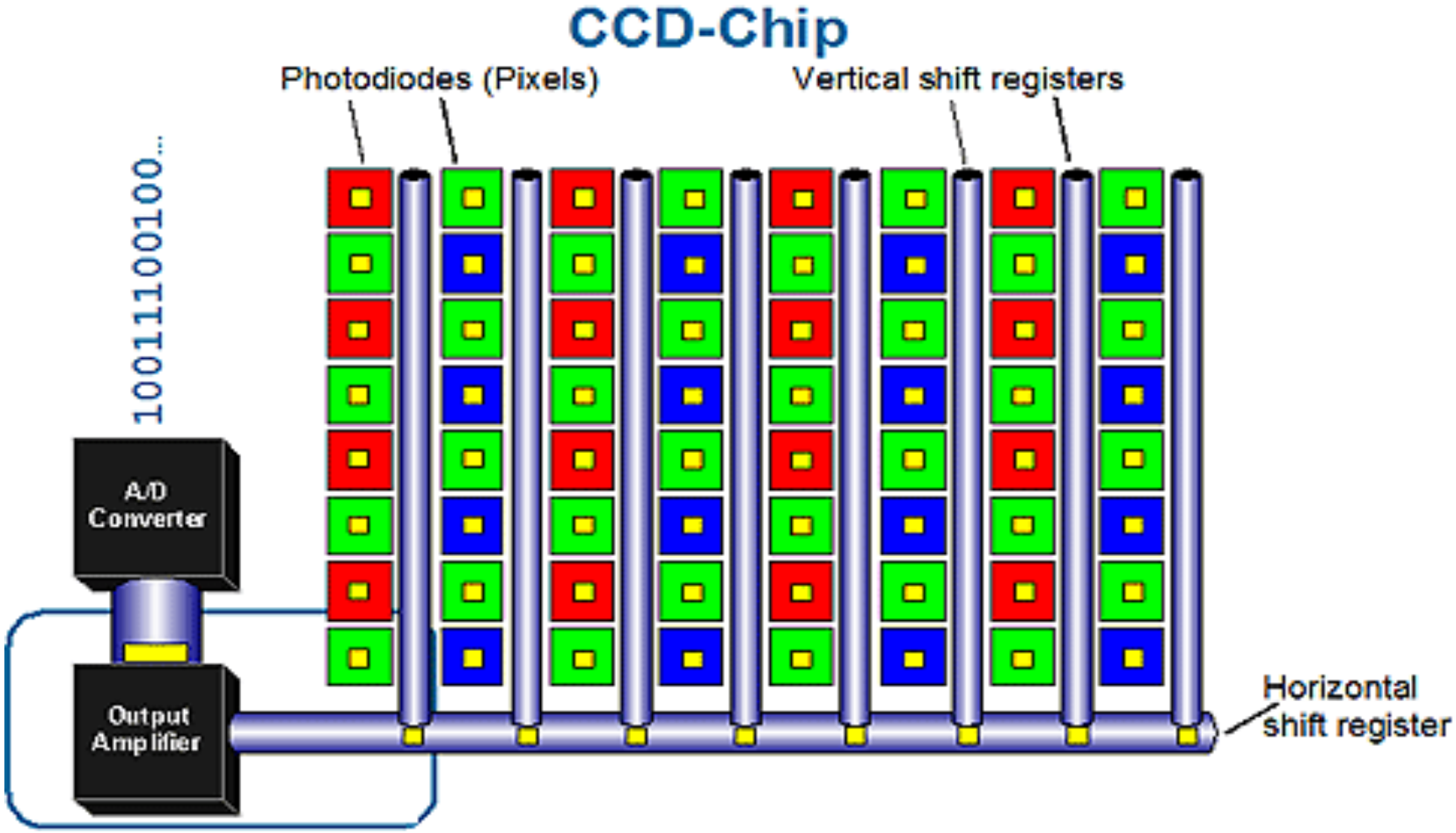
speaking of servoing...

Visual Servoing

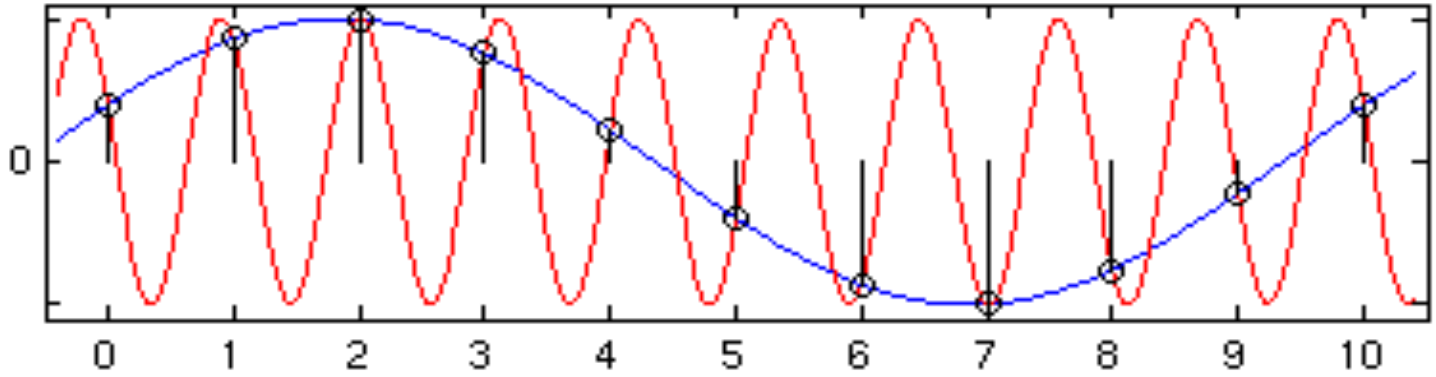
Details

- 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

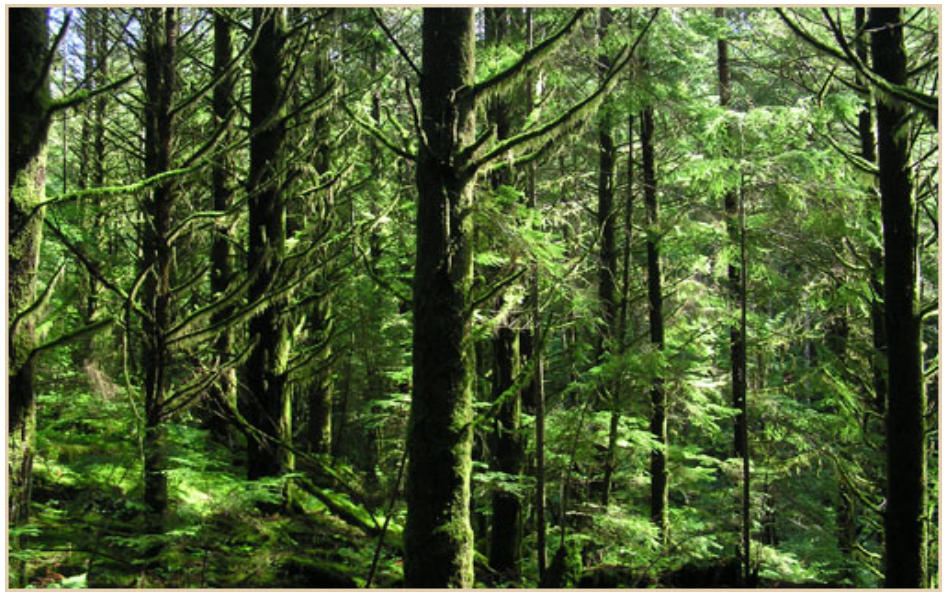
Aliasing: Moiré Patterns

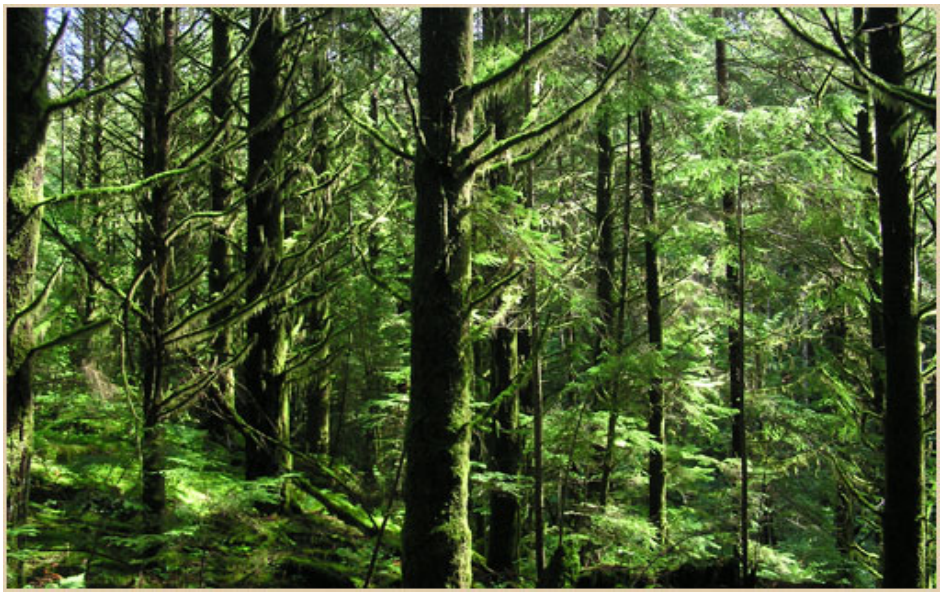
Key problems

- 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



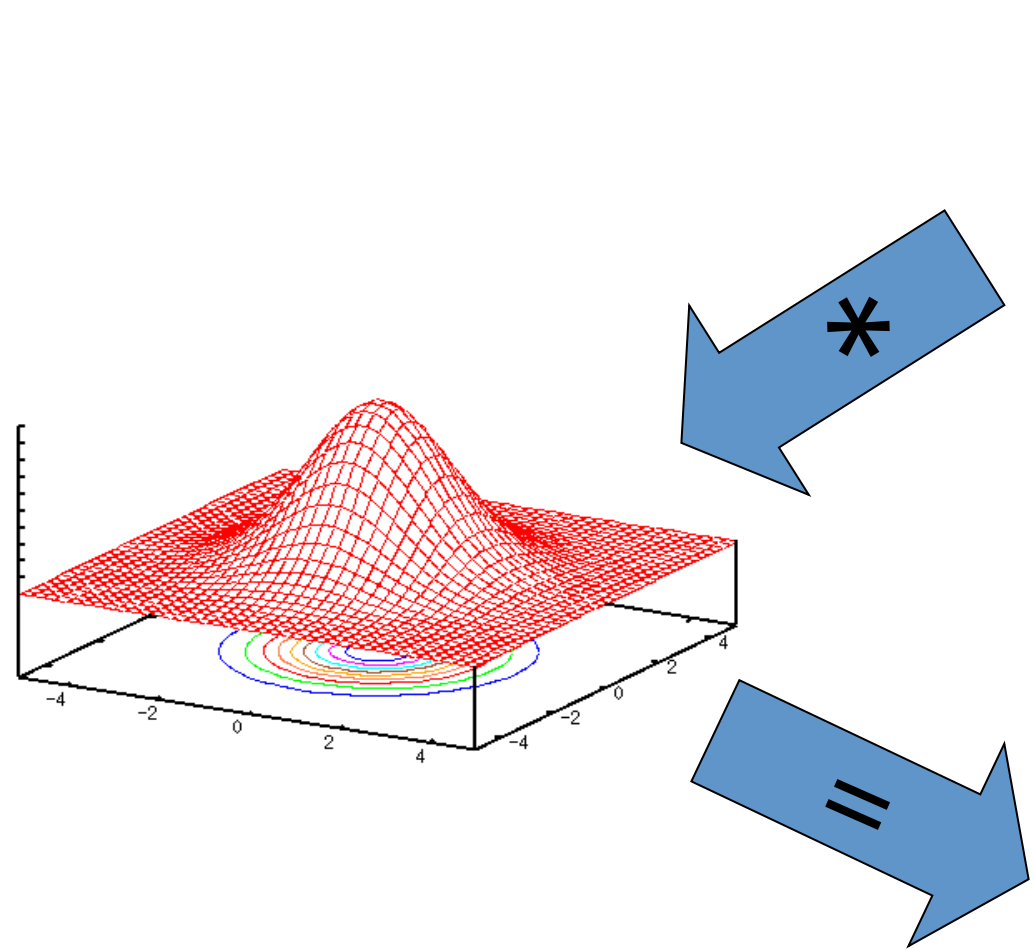


Correspondence

From I_1

From I_2

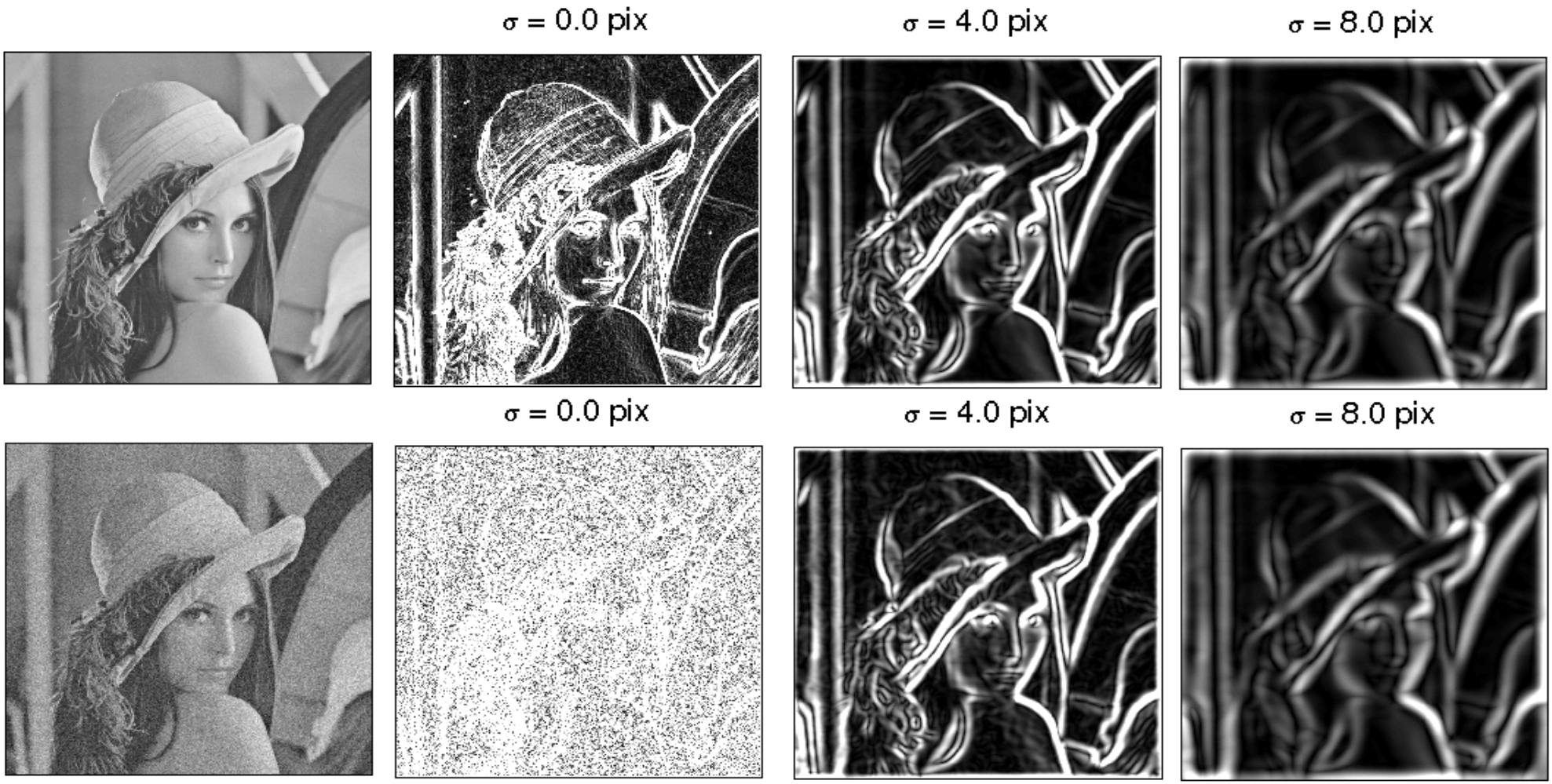
Gaussian Blur



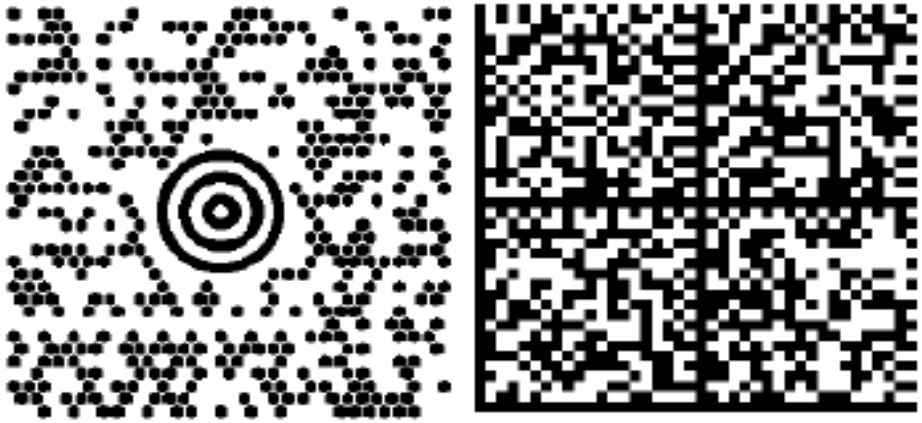
Gaussian Blur and Noise

Gaussian Blur and Noise

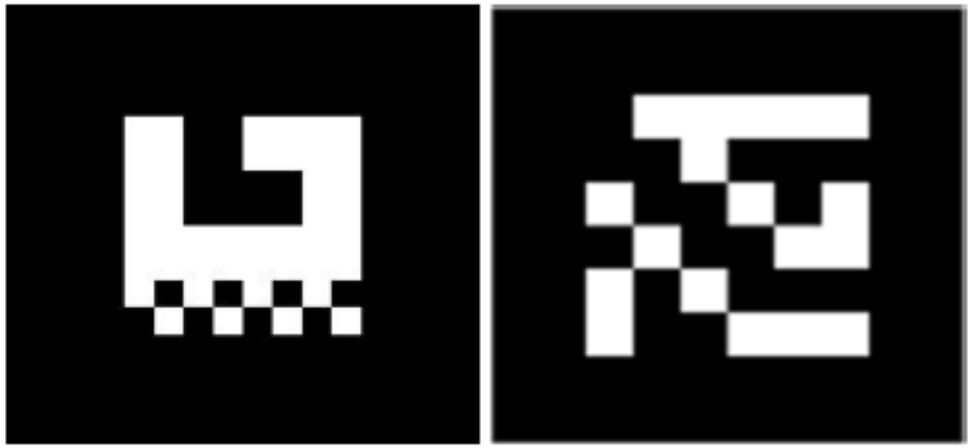
Gaussian Blur, Noise, Sobel



Fiduciary Markers/Fiducial



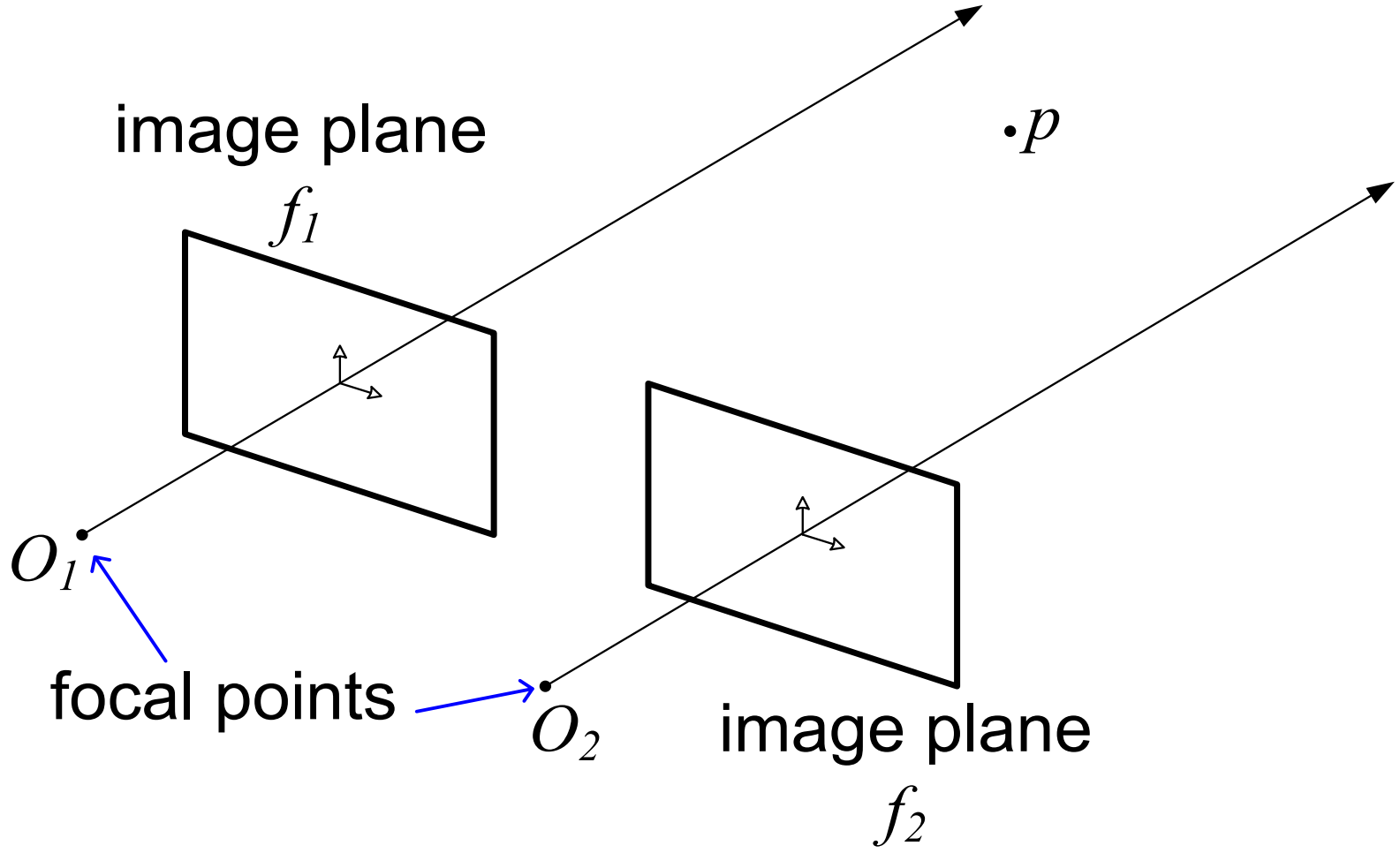
(a) MaxiCode (b) DataMatrixSymbol



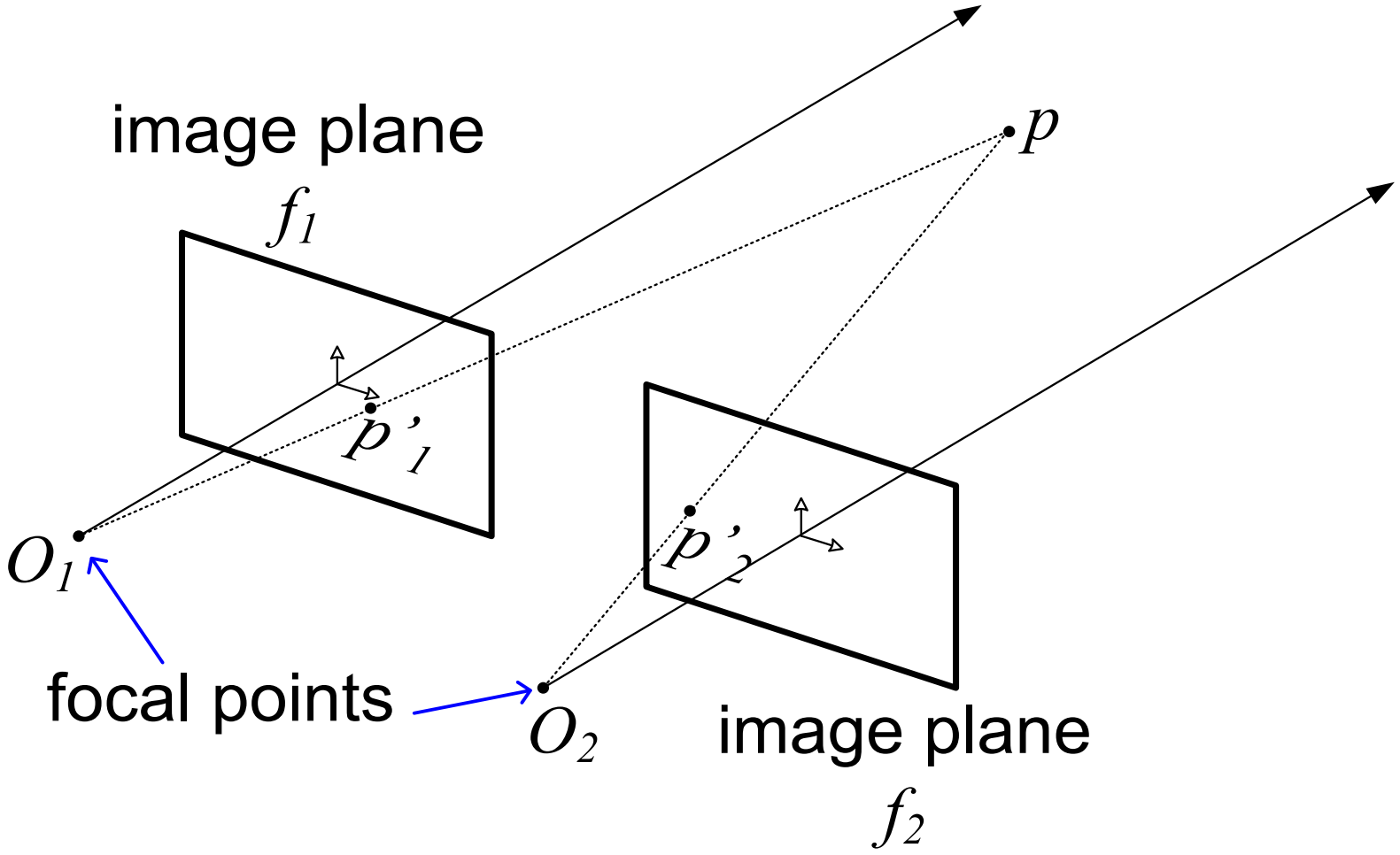
(c) ARToolkit (d) ARTag

Fourier Tag

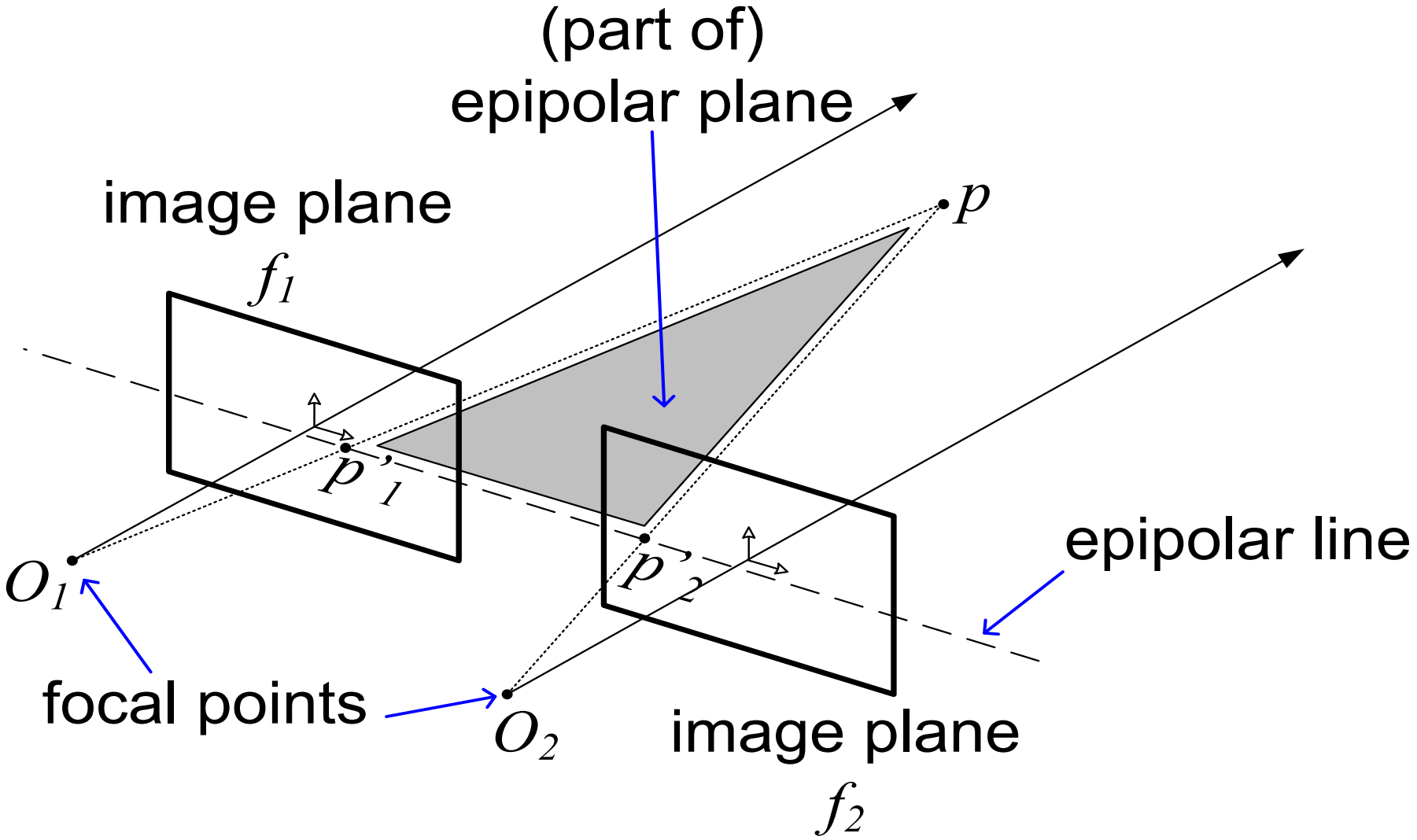
Stereo Vision: Pinhole Camera



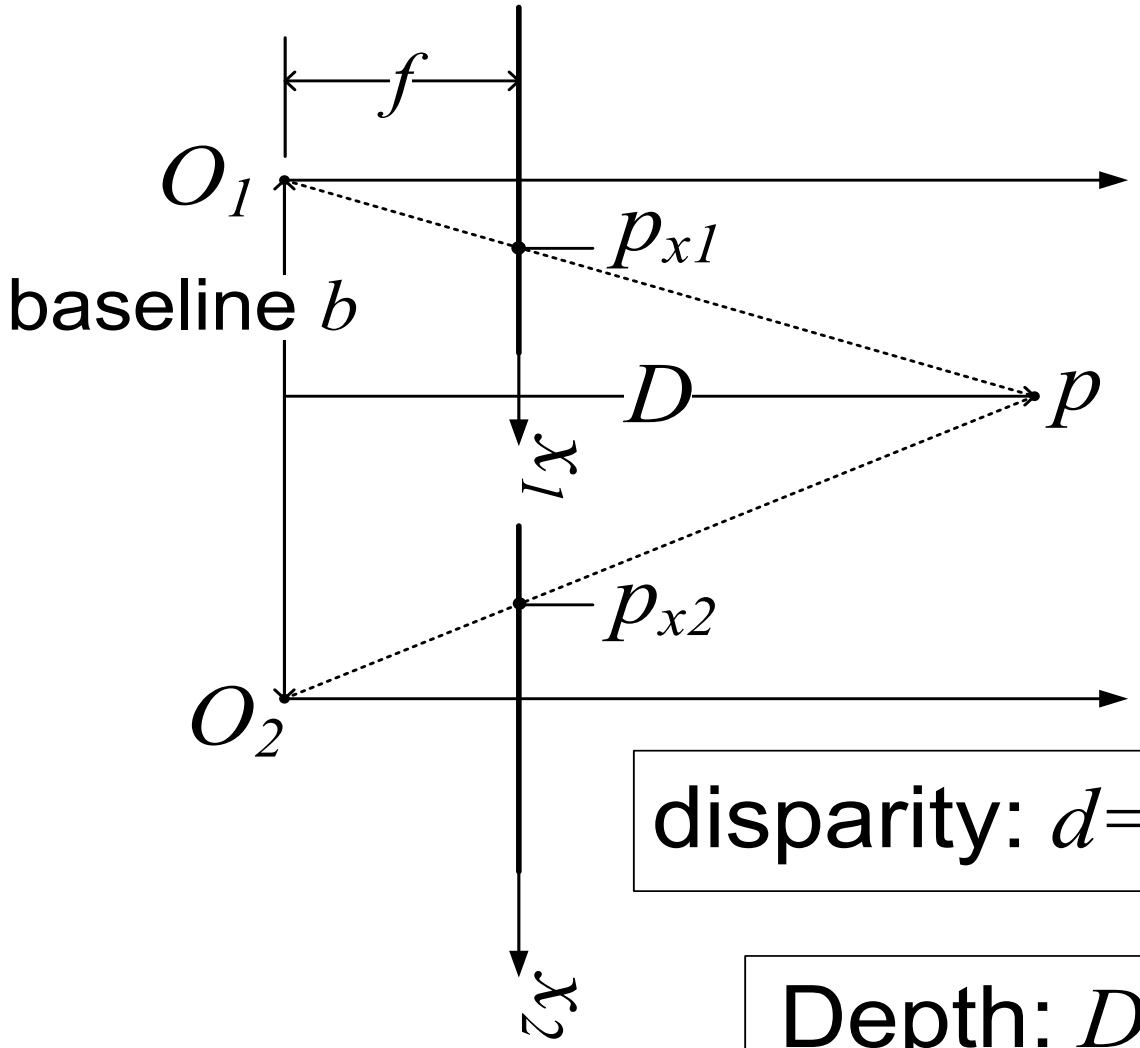
Stereo Vision: Pinhole Camera



Stereo Vision: Pinhole Camera



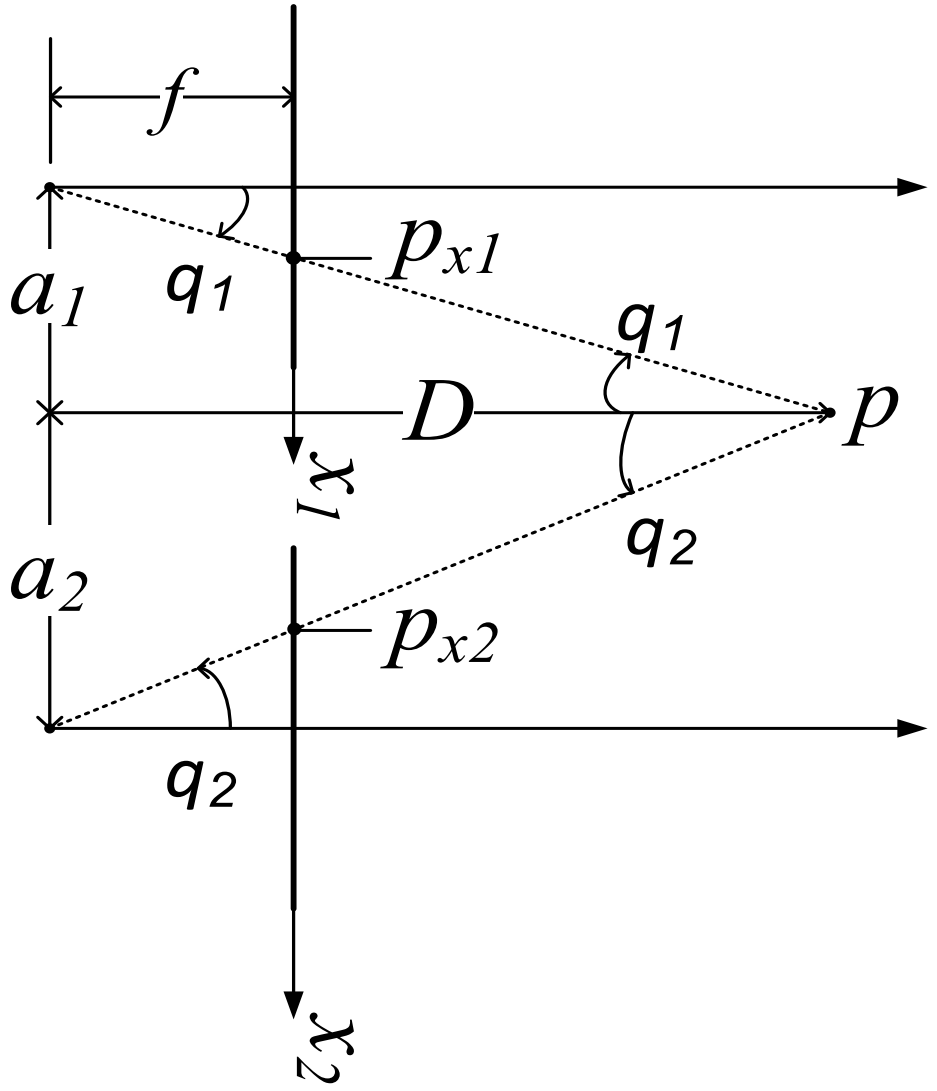
Stereo Vision: Pinhole



disparity: $d=p_{x1}-p_{x2}$

Depth: $D=fb/d$

Stereo Vision: Pinhole



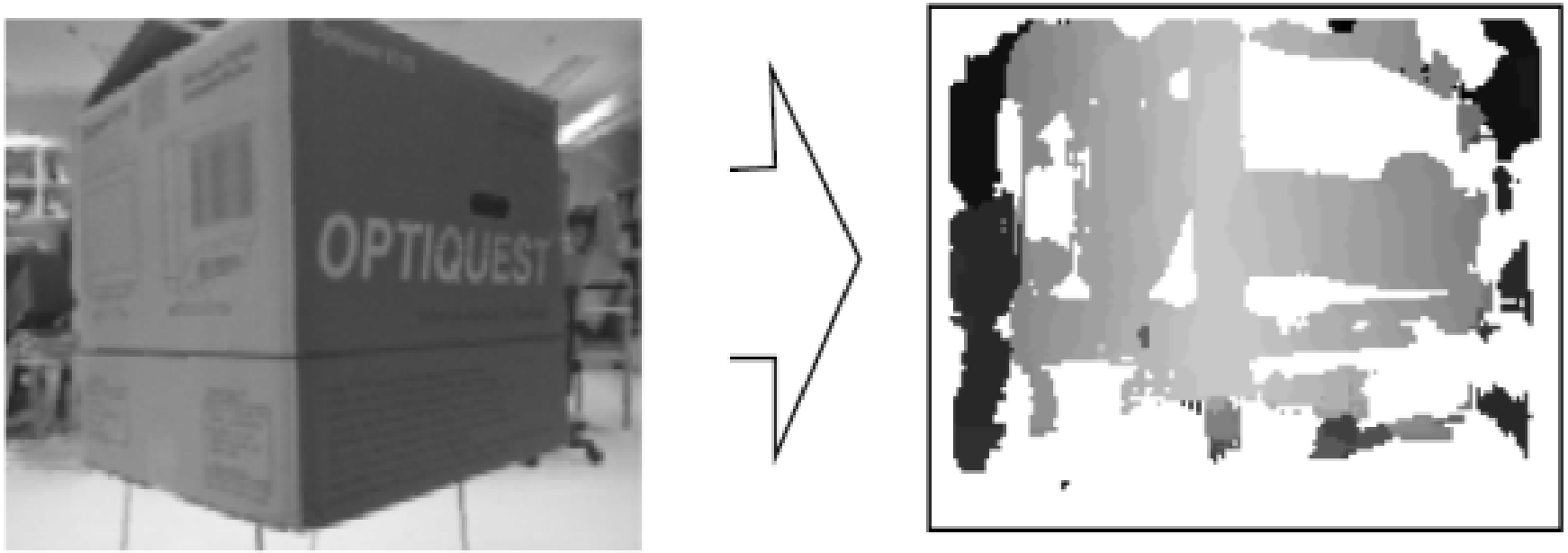
$$\frac{p_{x1}}{f} = \frac{a_1}{D}$$

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

$$a_1 + a_2 = b$$

Large Baseline

Stereo: Disparity Map

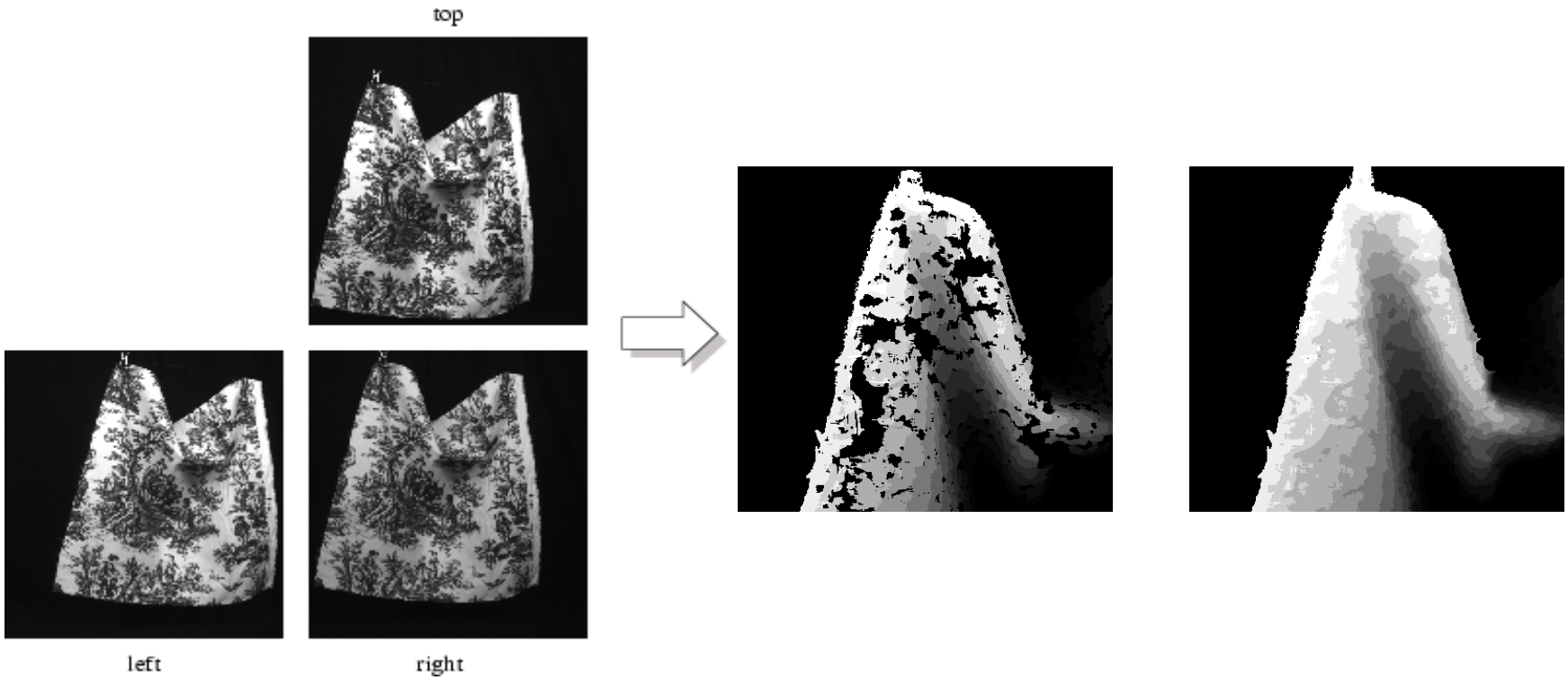


Using real-time stereo vision for mobile robot navigation

Don Murray Jim Little

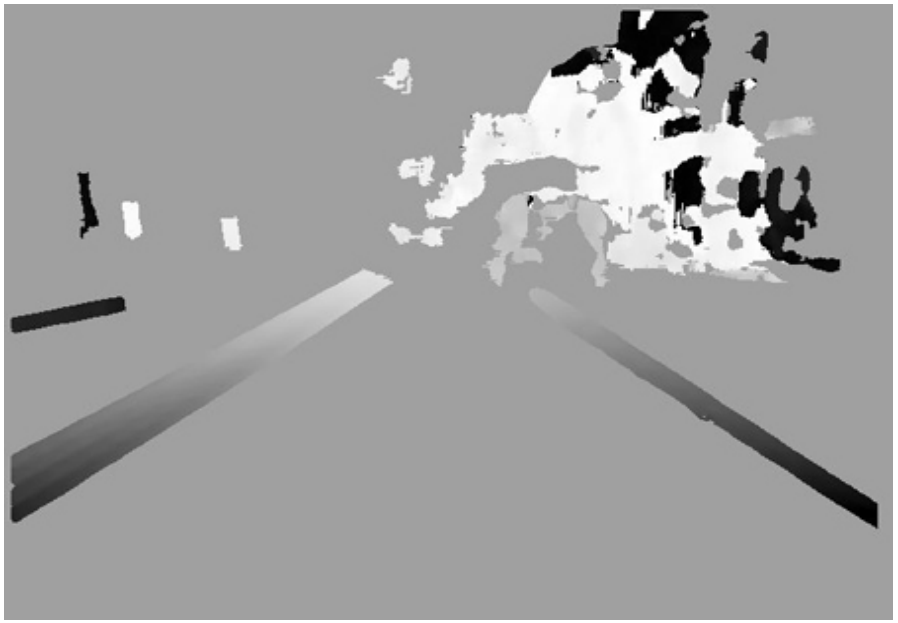
Computer Science Dept.
University of British Columbia
Vancouver, BC, Canada V6T 1Z4

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:

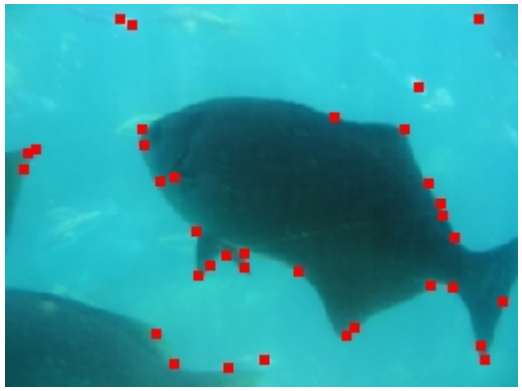
  http://vision.middlebury.edu/stereo/

  rank 43 different algorithms.

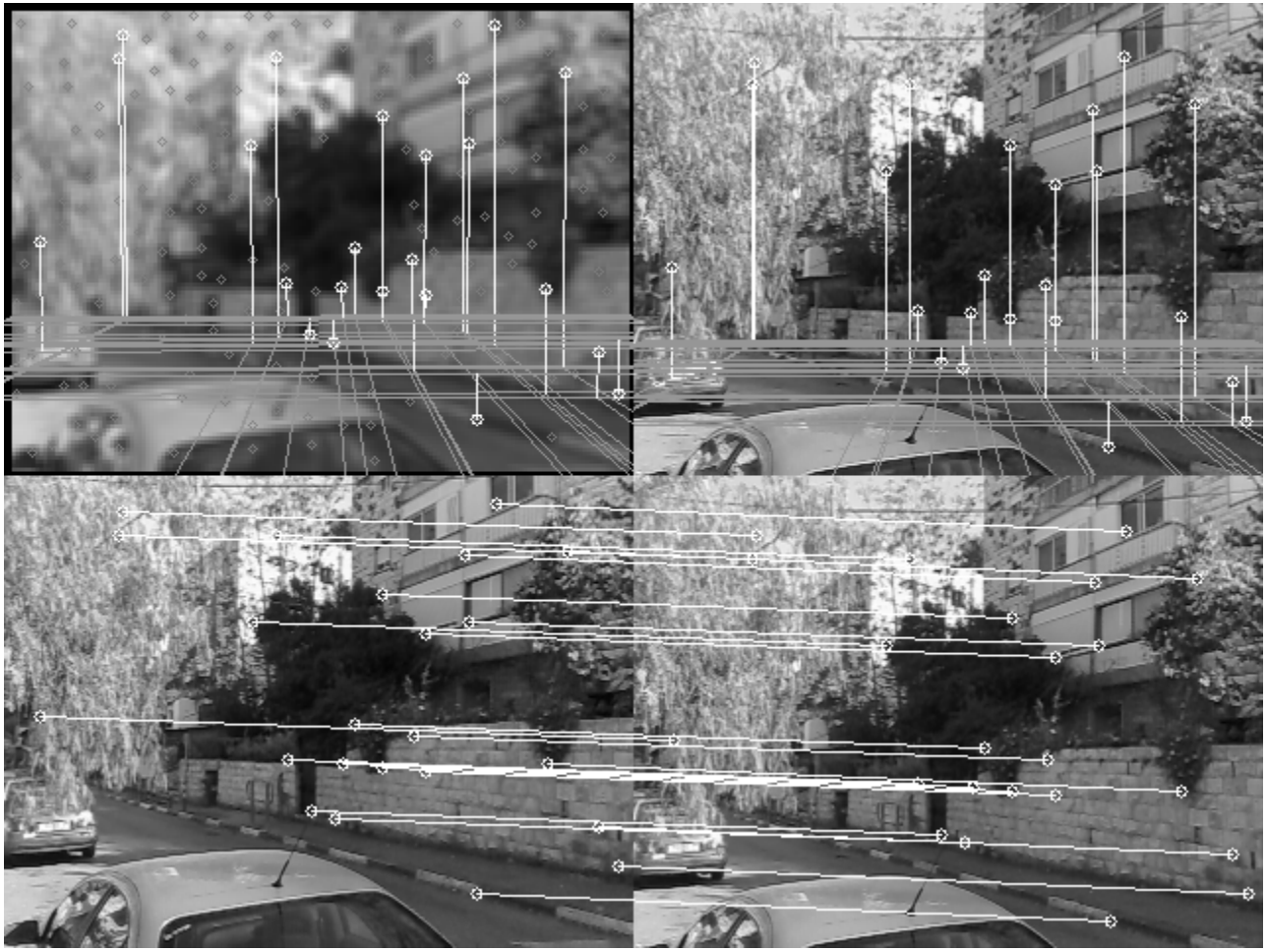
Good Feature

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

Harris Corners



SURF



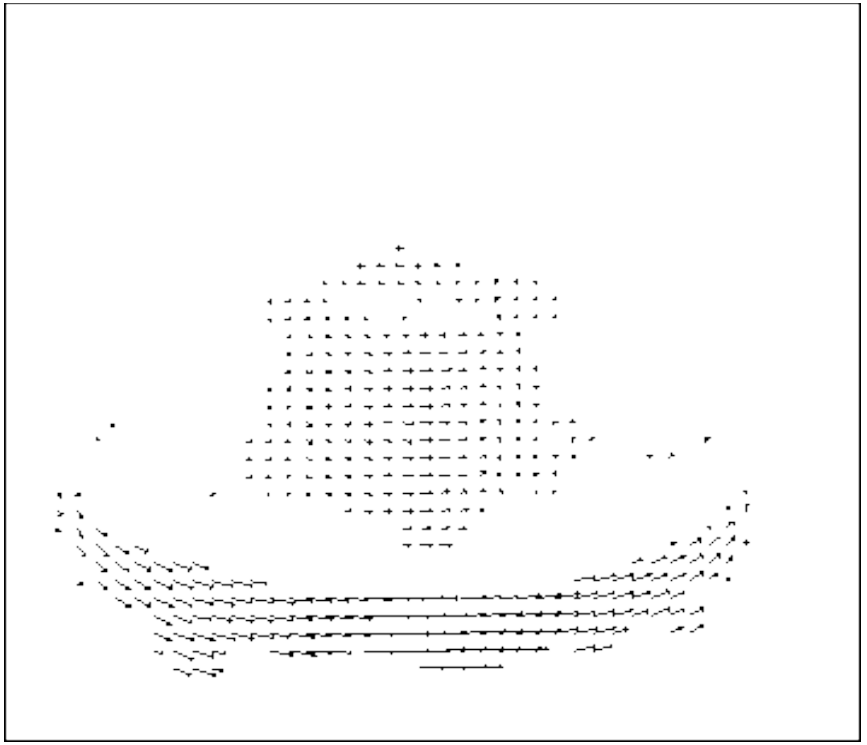
SIFT


BASSONCINI
Grisbì Almond Cookies
Peso Netto 250 g
NET WT 8.8 OZ

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.*

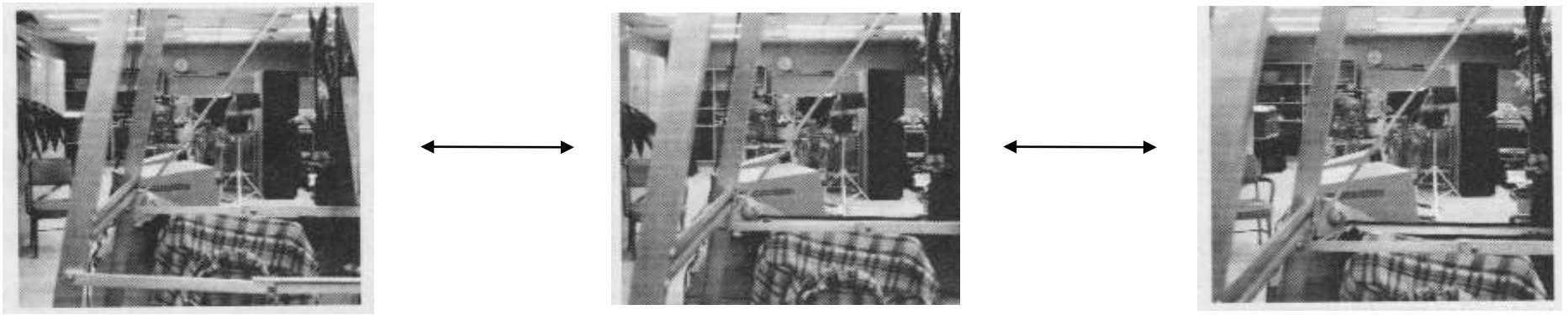
Optical Flow Field



Optical flow

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

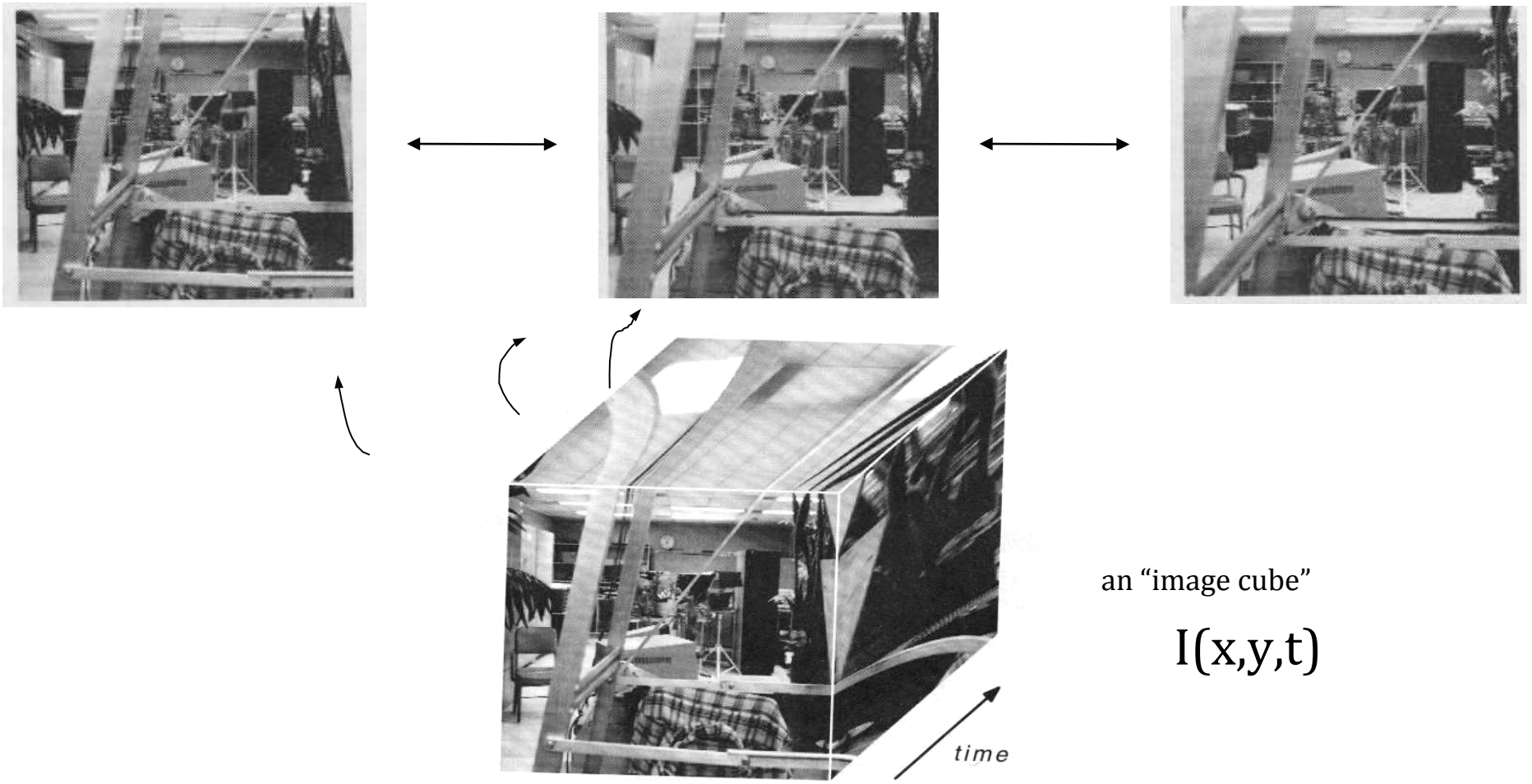
This next step might be to use the image motion to infer scene motion, robot motion or 3D layout.



time sequence of images

Optical flow

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

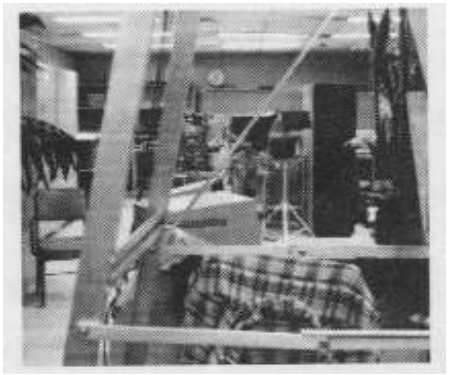


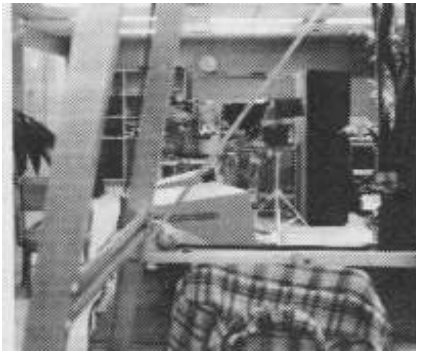
an "image cube"

$I(x,y,t)$

Optical flow

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





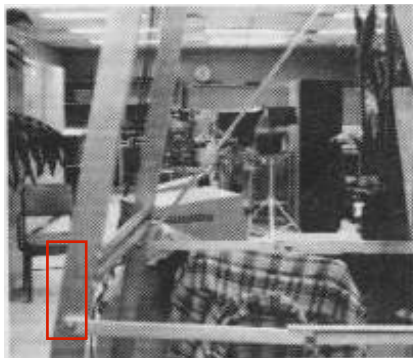
optical flow

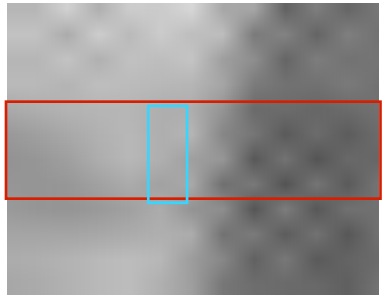
How ?

Optical Flow

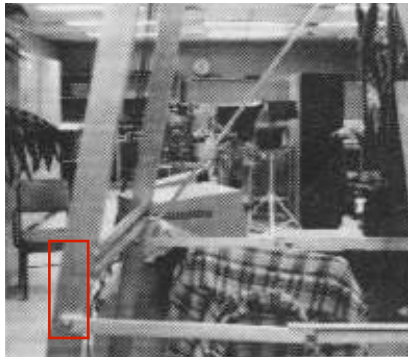
- By measuring the direction that intensities are moving...

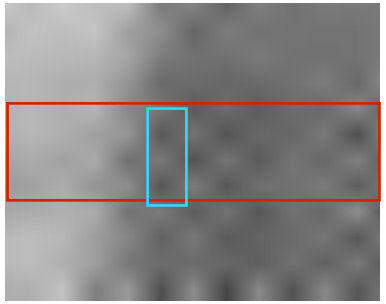
I(x,y,t)





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

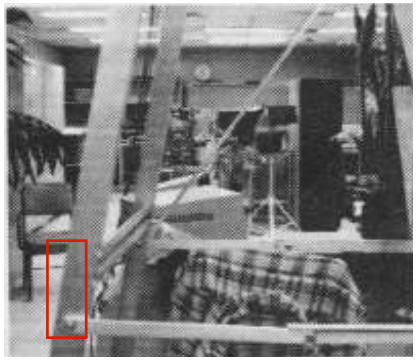
- How can we do this?
- Assume the scene itself is static.
- Find matching chunks in the images.
- An instance of *correspondence*.

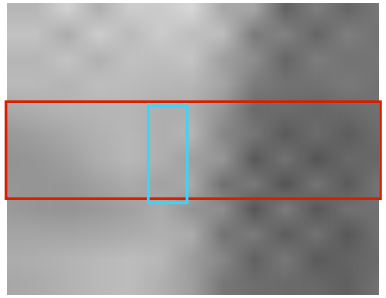
BUT

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

Optical Flow

By measuring the direction that intensities are moving...





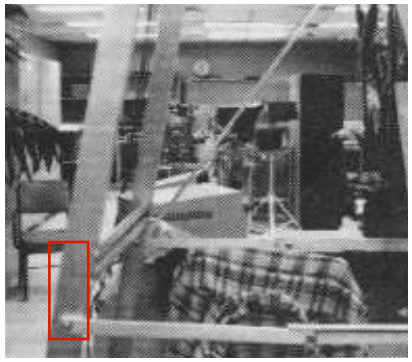
I(x,y,t)

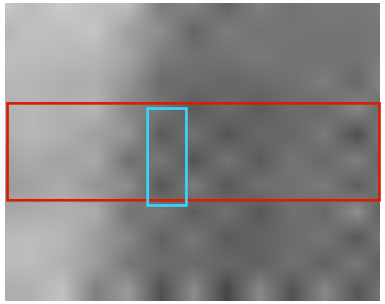
I(x,y,0)

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

I(0,0,0)

I(2,-1,0)





I(x,y,1)

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

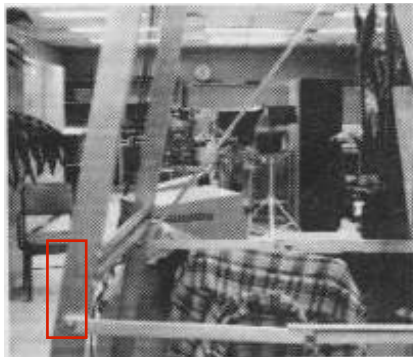
I(0,0,1)

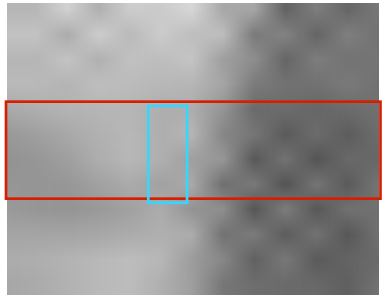
We can estimate things ...

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

Optical Flow

By measuring the direction that intensities are moving...





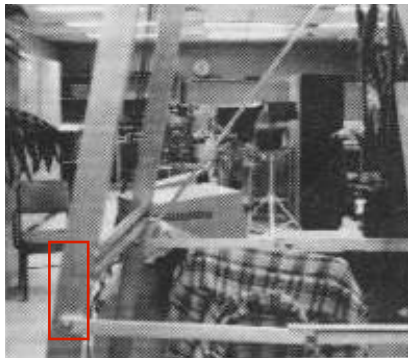
I(x,y,t)

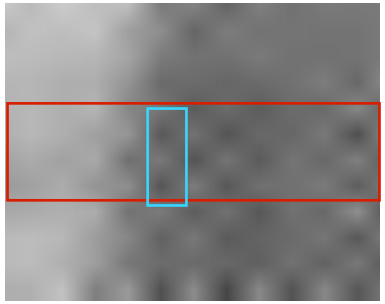
I(x,y,0)

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

I(0,0,0)

I(2,-1,0)





I(x,y,1)

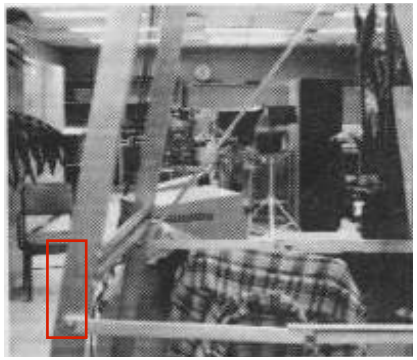
90	90	70	40	25
90	70	40	40	25
90	70	**40**	40	25
90	70	40	40	20
70	50	40	30	15

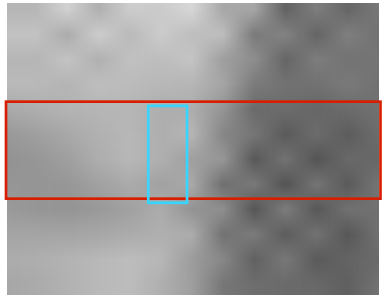
I(0,0,1)

We can estimate things like $\frac{dI}{dx} = I_x$ 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...





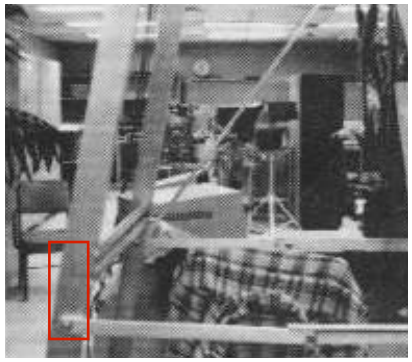
I(x,y,t)

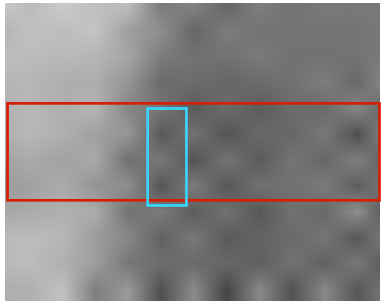
I(x,y,0)

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

I(0,0,0)

I(2,-1,0)





I(x,y,1)

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

I(0,0,1)

We can estimate things like

$$\frac{dI}{dx} = I_x \qquad \frac{dI}{dy} = I_y \qquad \frac{dI}{dt} = I_t$$

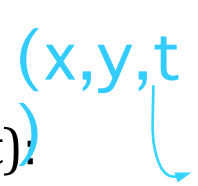
so...

Measuring Optical Flow

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

Simplest assumption (constant brightness constraint):

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



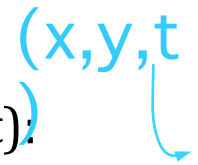
99	90	90	70	40
95	90	70	40	40
90	90	**70**	40	40
90	90	70	40	40
90	70	50	40	30

Measuring Optical Flow

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

Simplest assumption (constant brightness constraint):

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



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

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

Measuring Optical Flow

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

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(x,y,t)

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

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

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

intensity-flow equation

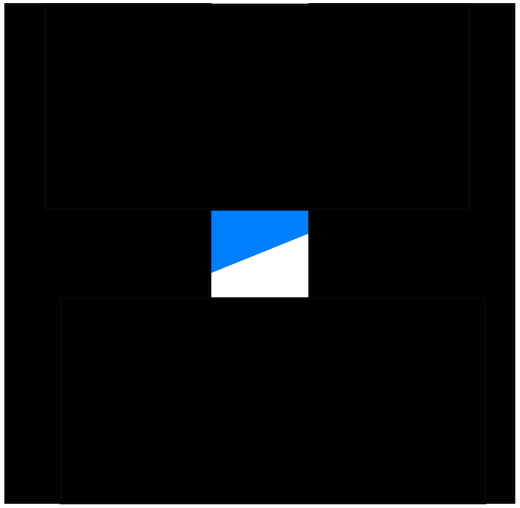
good and bad...

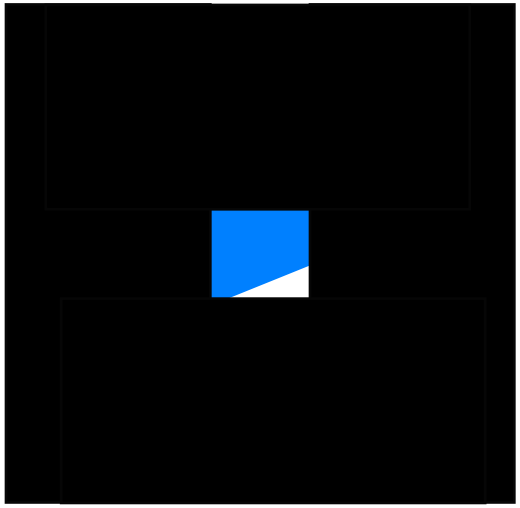
The “aperture” problem

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

- 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...





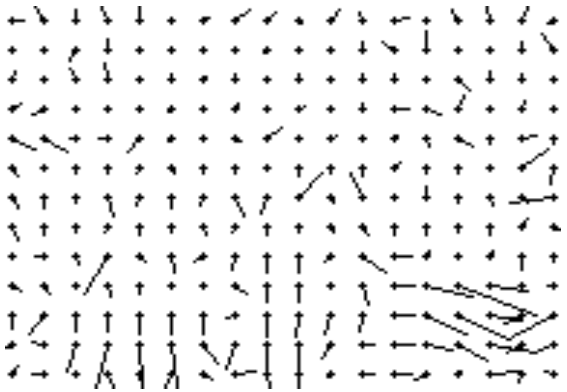
The “aperture” problem

→ It is only possible to find optical flow in one direction...

*at any **single** point in the image !*

img1

img2



raw optical flow

smoothed for ten iterations

Smoothing can be done by incorporating neighboring points’ information.

Optical Flow Application

- Visual Odometry
  - Wheel slip detection on future Mars Rovers

Image Downsampling