Computer Vision

COMP417 – Introduction to Robotics and Intelligent Systems

Why vision?

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

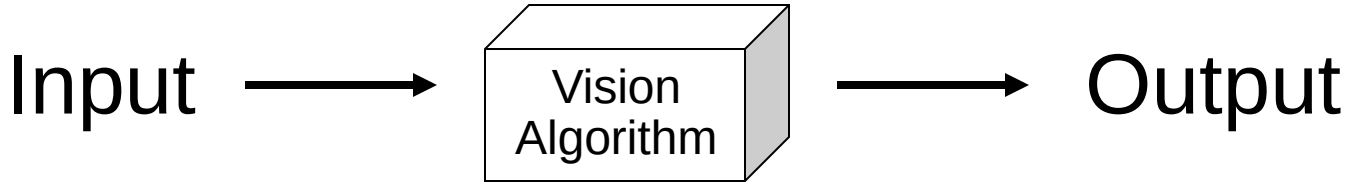
So, what's the problem?

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

Problems:

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

The “Vision Problem”



The “Vision Problem”

207 200 199 194 203 126 106 091 113 153 192 196 190 186 175
242 194 213 254 255 114 082 109 097 089 208 206 202 194 185
254 159 187 245 248 128 197 191 166 102 248 251 233 223 246
255 159 191 245 249 123 113 047 124 149 255 253 239 143 250
255 184 191 249 249 126 022 040 115 039 250 255 255 177 252
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253 254 169 241 253 141 053 180 005 019 253 253 255 253 201
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013 049 076 059 032 028 174 197 182 060 021 021 121 101 062
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255 206 194 255 246 141 019 021 035 026 250 255 255 184 255
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221 217 180 213 243 081 052 029 055 023 250 249 244 221 210
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229 224 183 213 121 036 076 034 069 073 116 248 236 220 214
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221 215 190 084 122 070 011 018 075 013 076 079 146 227 216
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215 222 033 092 067 063 031 023 070 025 125 055 136 224 226
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Looking at vision

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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255	172	201	255	249	123	092	040	094	106	255	253	239	150	254
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252	238	180	218	251	106	116	181	140	024	250	255	255	255	200
248	248	169	227	252	111	066	118	061	021	252	251	255	255	142
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255	221	179	248	227	111	083	041	061	083	240	249	243	232	253
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230	223	185	185	112	079	008	124	158	125	119	119	232	225	232
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223	217	132	046	072	076	056	048	013	182	073	076	083	215	219
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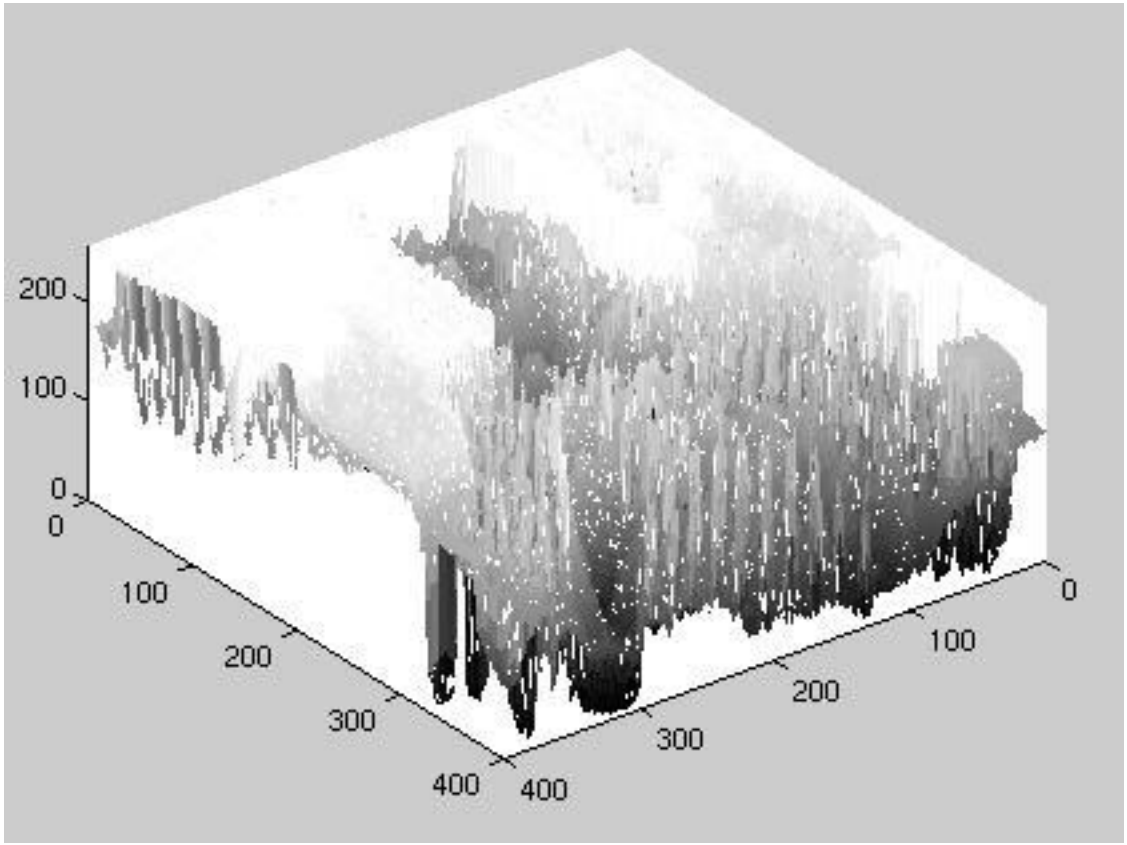

Looking at vision

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207 200 194 194 203 130 105 095 107 153 192 196 190 186 175
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254 170 204 255 248 122 153 135 111 081 252 253 233 232 250
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Looking at vision

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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
254 170 204 255 248 122 153 135 111 081 252 253 233 232 250
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The “Vision Problem”

Input → Vision Algorithm → Output

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
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020 067 073 058 055 076 069 050 074 064 065 066 066 059 023
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 can of spam."

does need information about what to do...

"Run Away!!"

reactive

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

environmental interactions

deliberative

What does a robot need ?

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

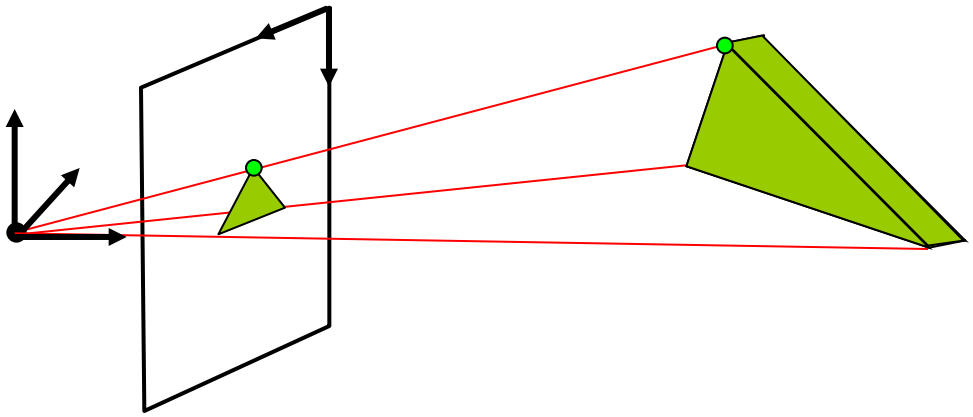
squeezes away one dimension

Ill-posed

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

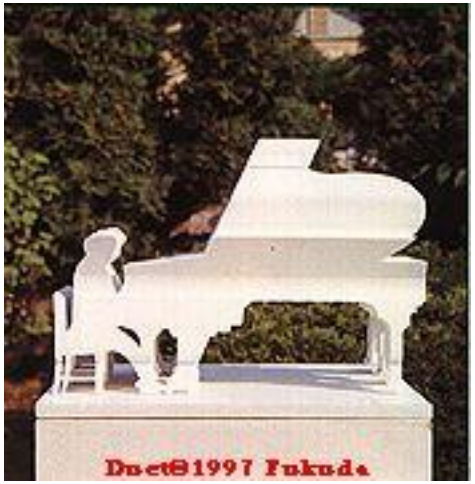
The vision problem in general...

- 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



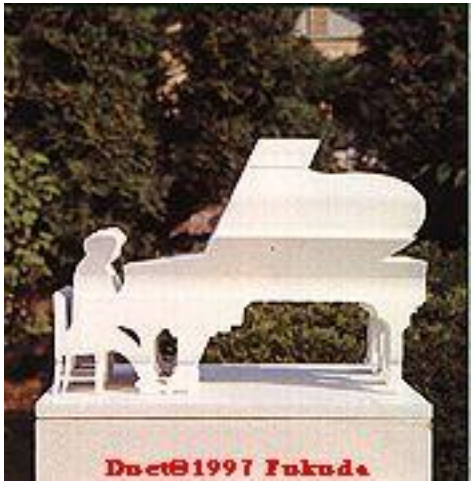
Ill-posed

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



Ill-posed

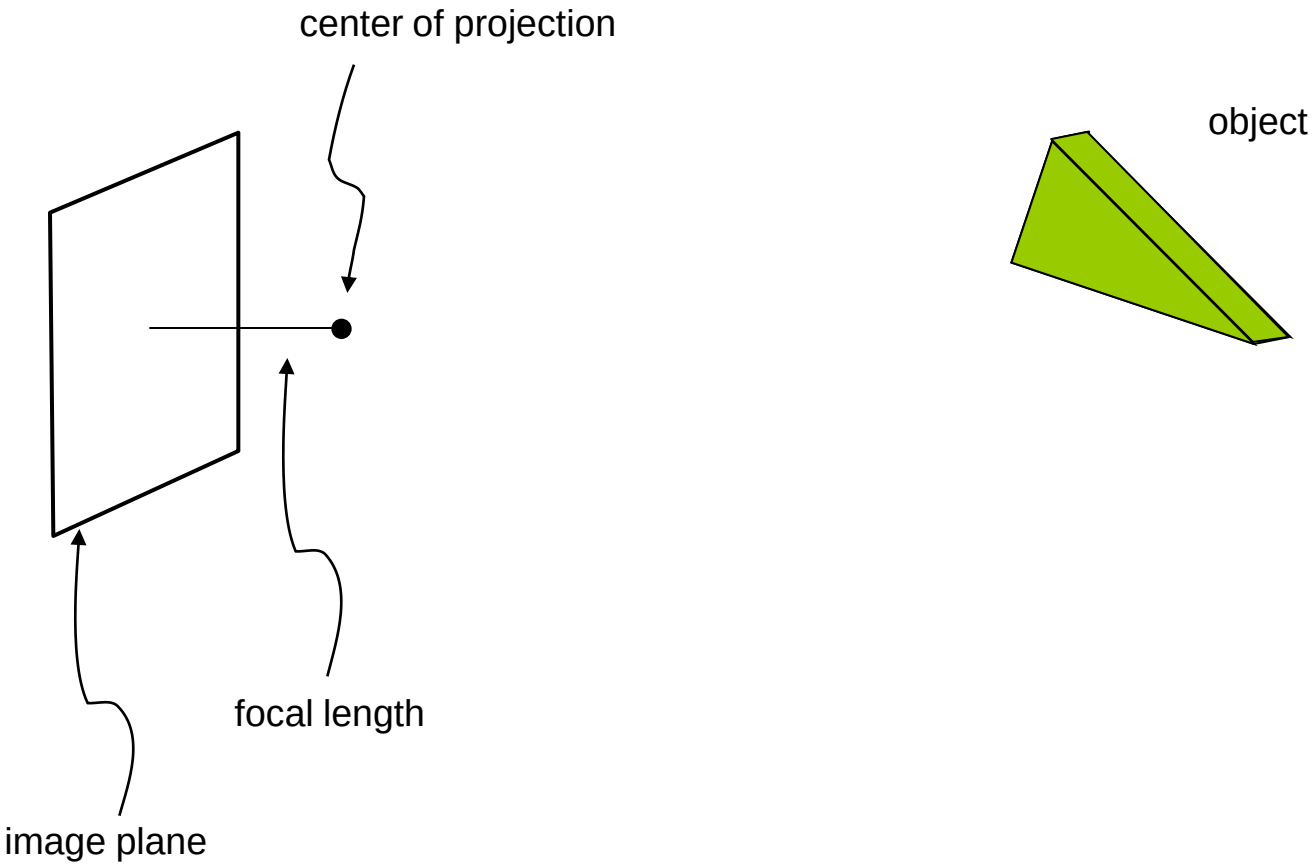
• In trying to extract 3d structure from 2d images, vision is **an *ill-posed* problem**.



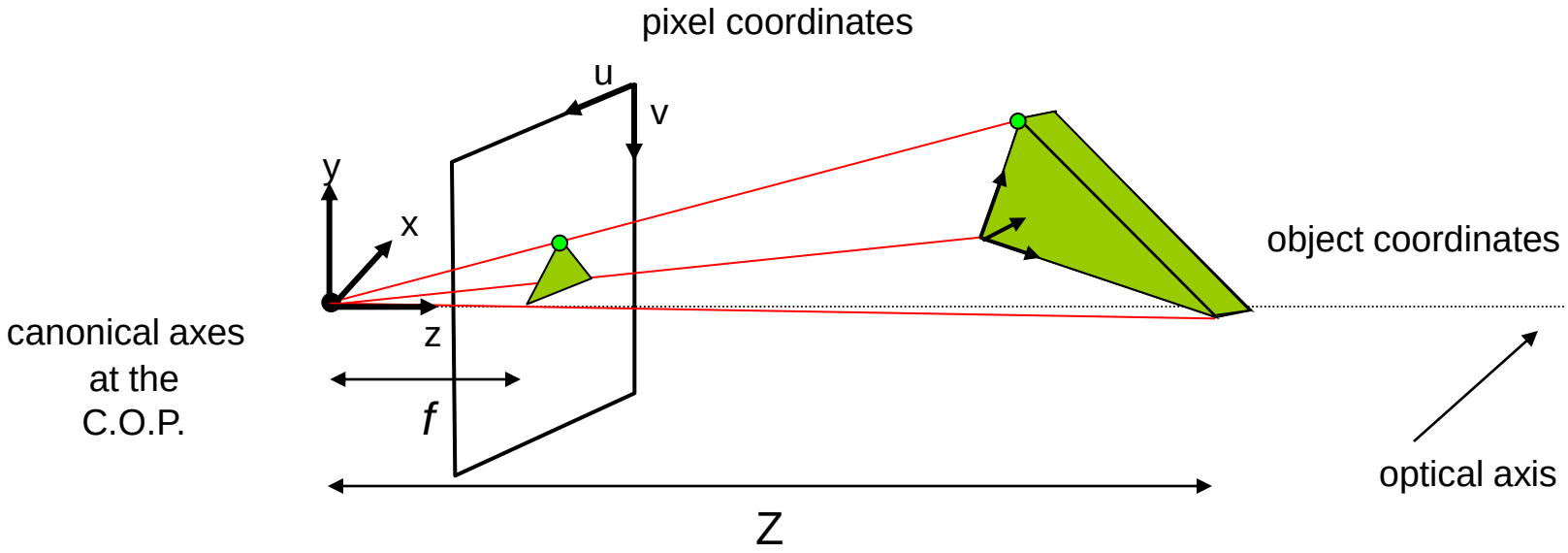
- An image isn’t enough to disambiguate the many possible 3d worlds that could have produced it.

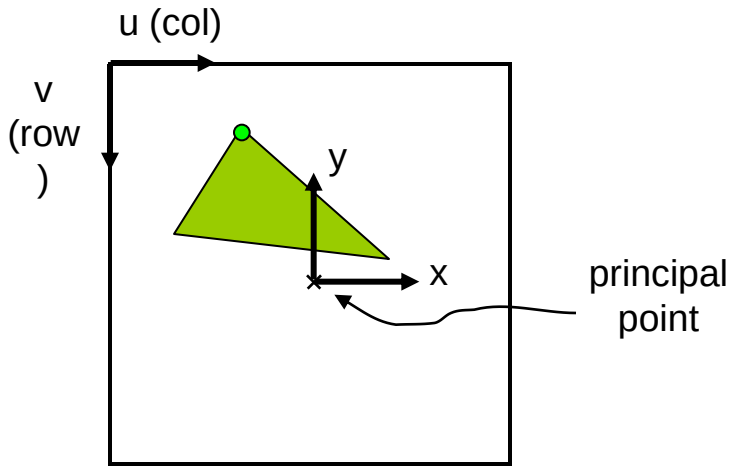
Camera Geometry

3d → 2d transformation: perspective projection



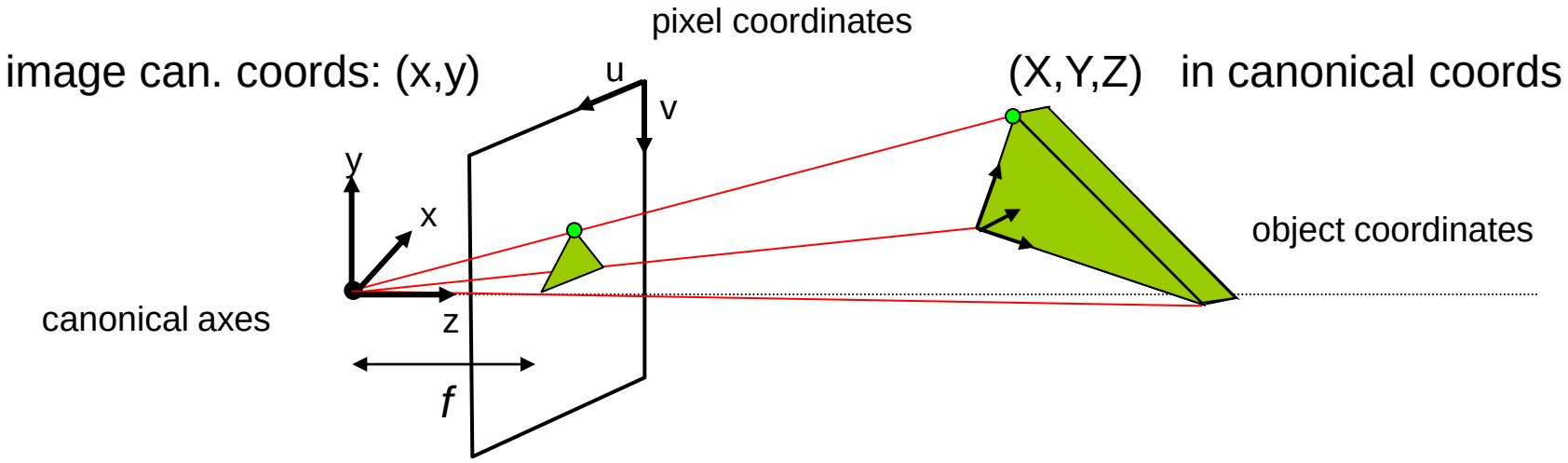
Coordinate Systems



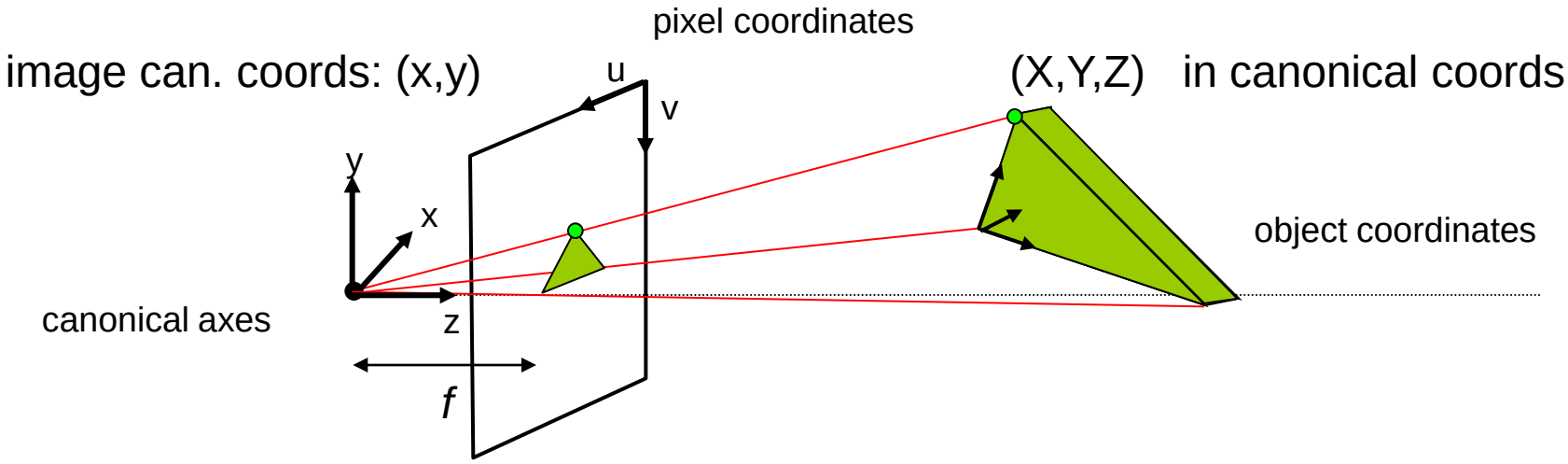


Add coordinate systems in order to describe feature points...

Coordinate Systems



From 3d to 2d



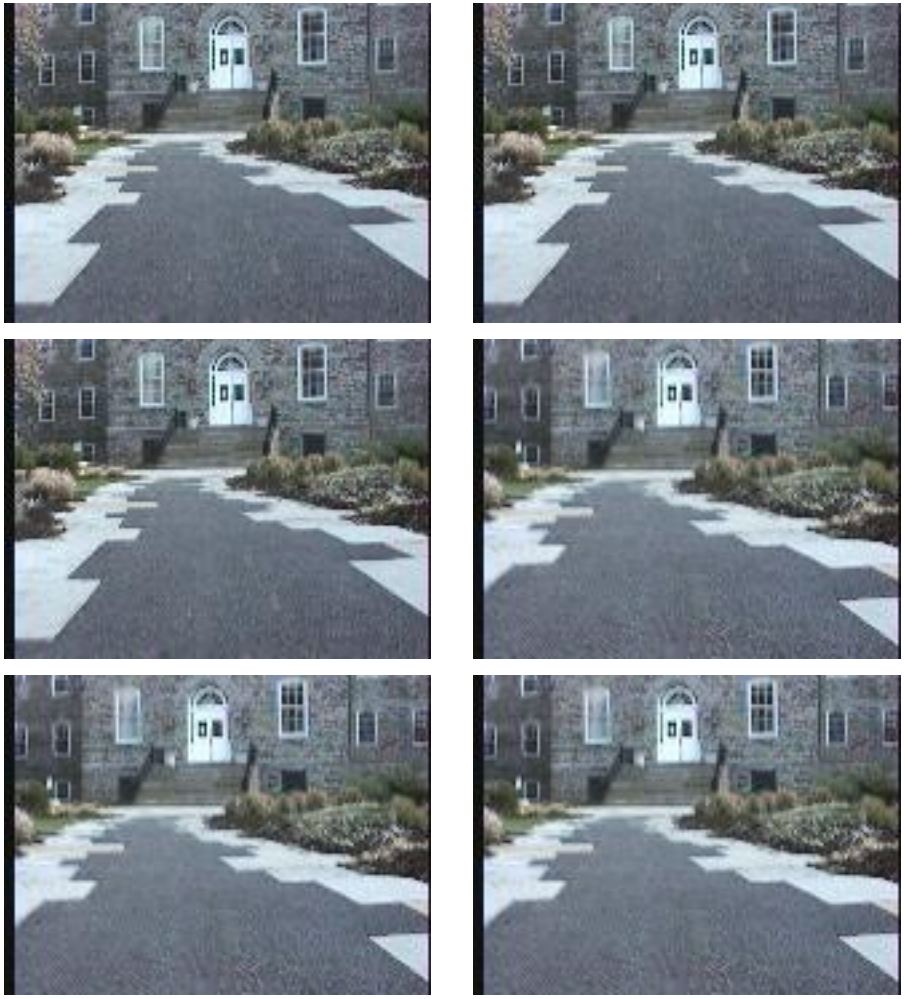
$$x = \frac{f\,X}{Z} \qquad y = \frac{f\,Y}{Z}$$

a nonlinear transformation

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

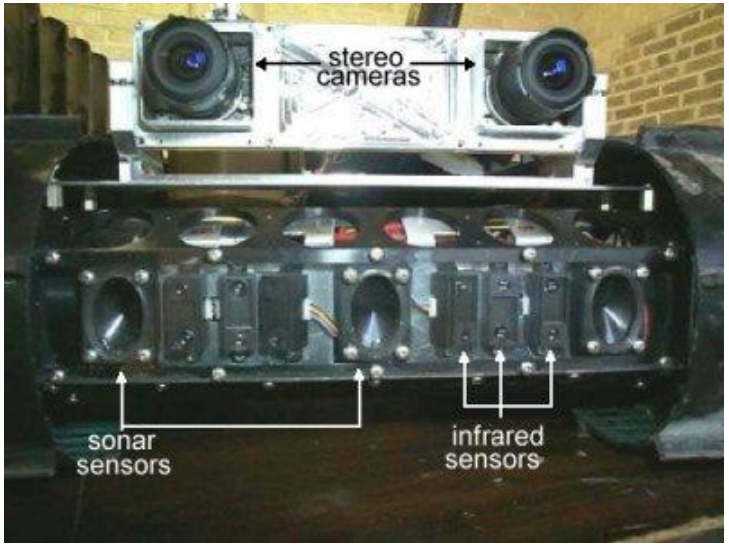
A Vision “solution”

- If interpreting a single image is difficult...



What about more ?!

multiple cameras



multiple times

Robot vision sampler

A brief overview of robotic vision processing...

(1) Image streams → simplified via generality

(1) Image streams → simplified via specificity

(2) Stereo vision → (or beyond...)

(3) Incorporating vision within robot control

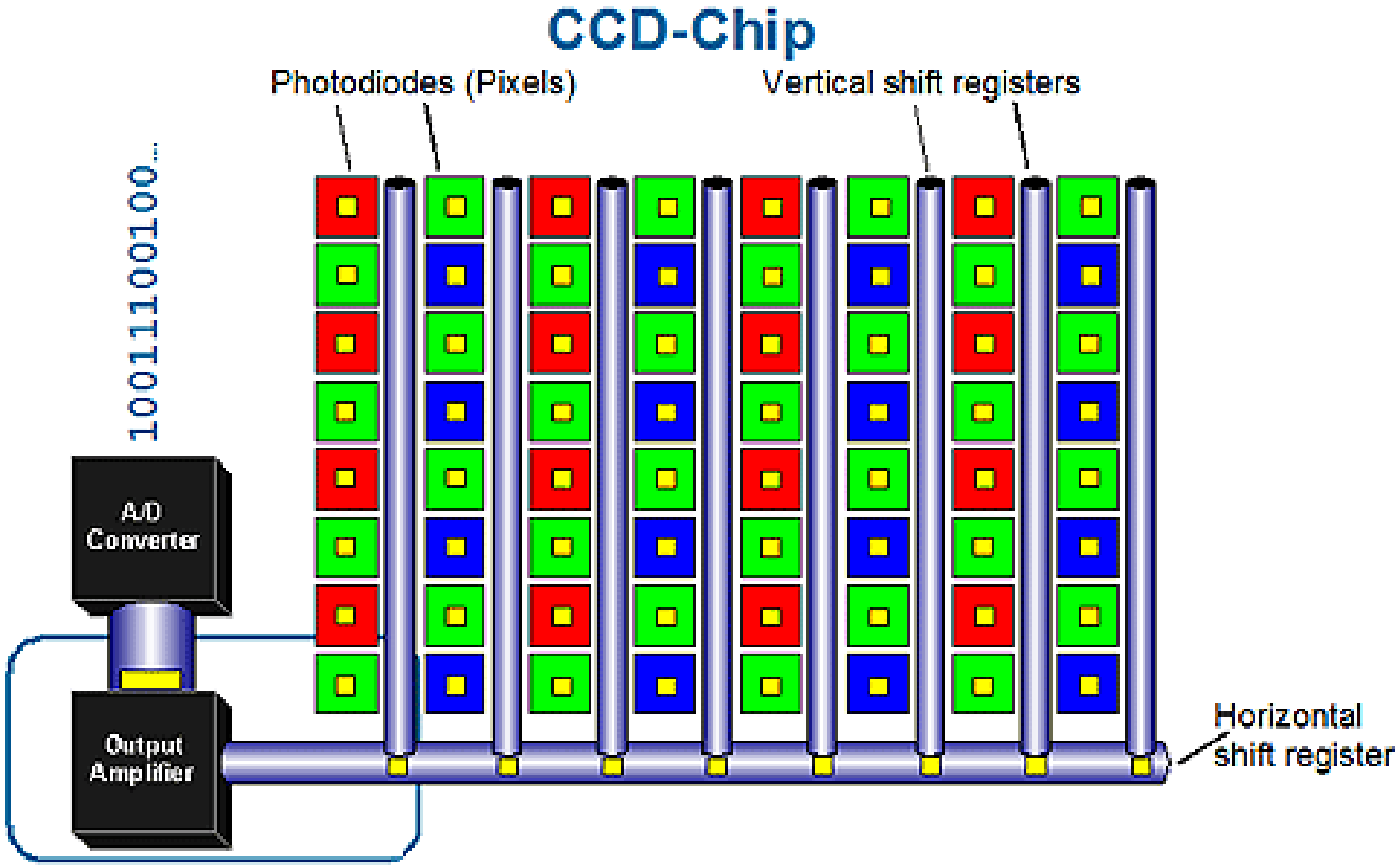
- → 3d reconstruction
- → Visual “servoing”

speaking of servoing...

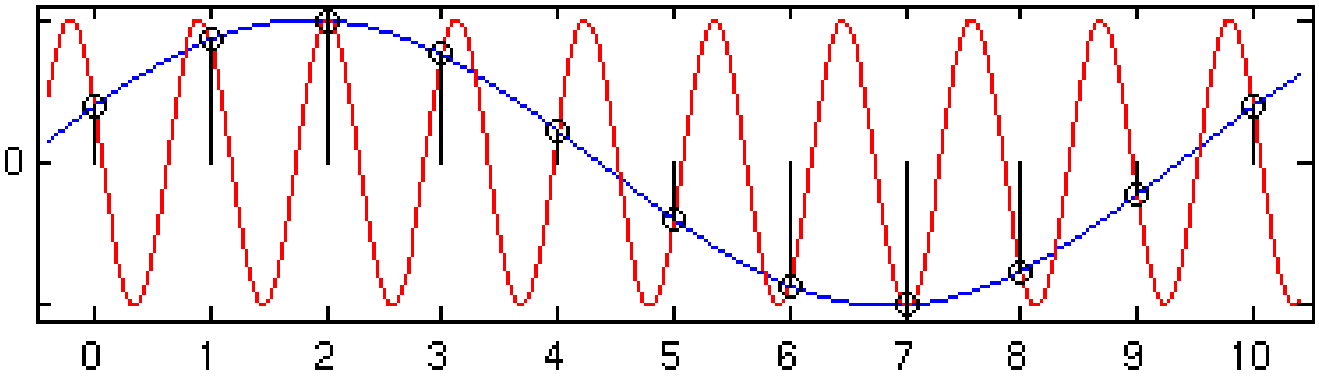
Details

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

CCD (Charge-Coupled Device)

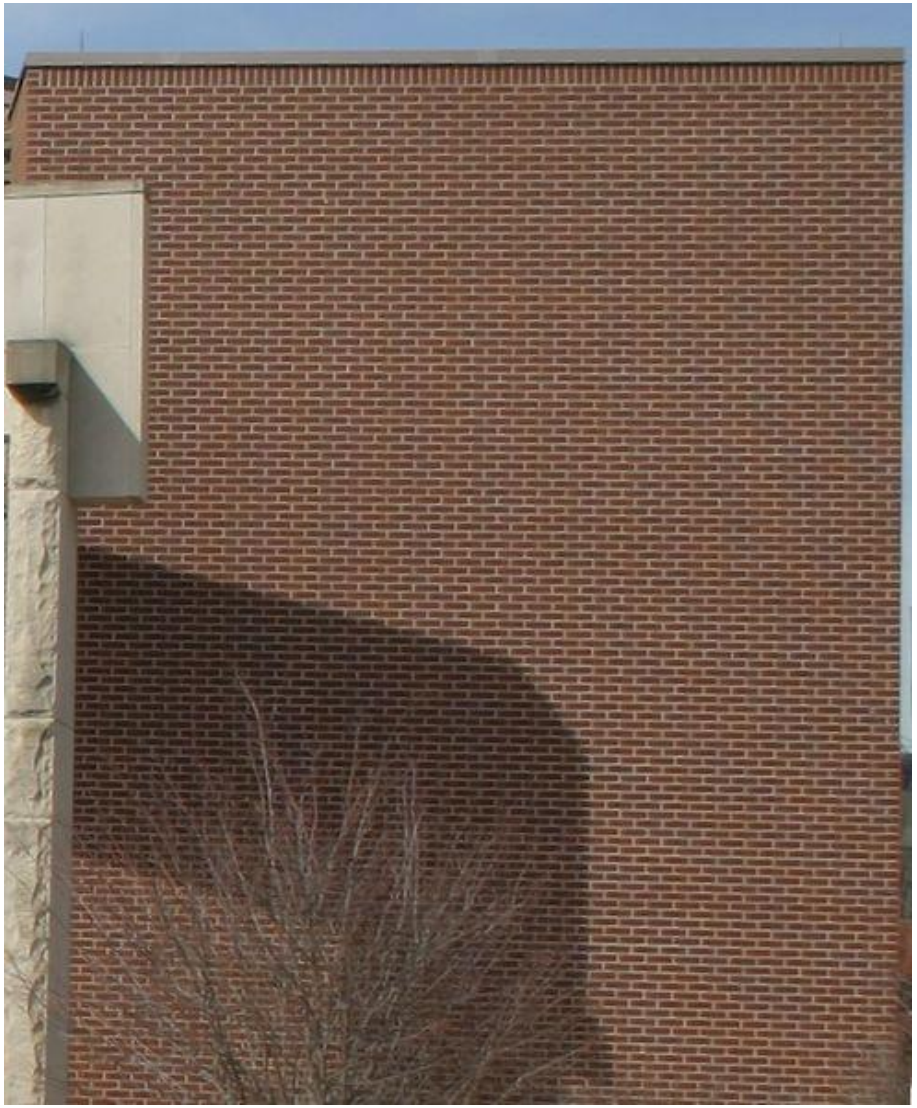


Aliasing.



- 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.”

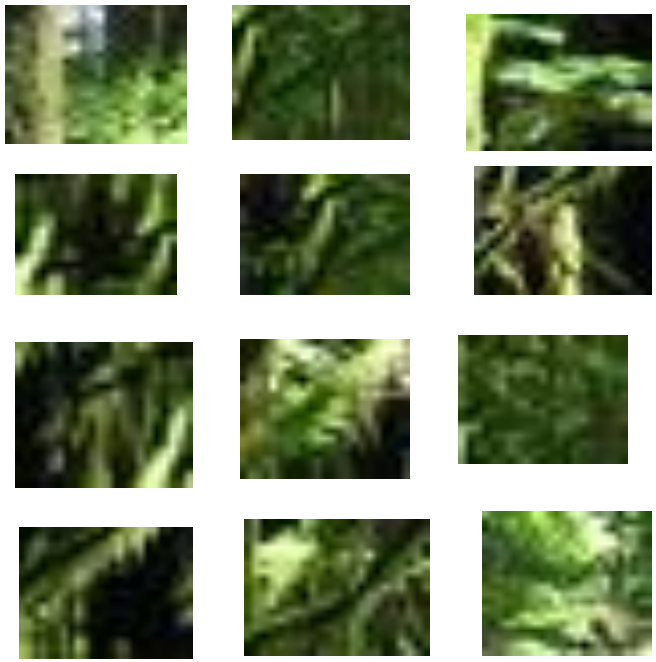
Correspondence Problem

Correspondence

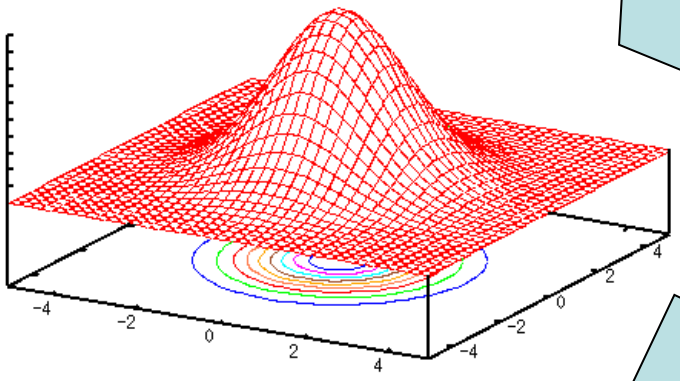
From I_1

From I_2

—?→



Gaussian Blur



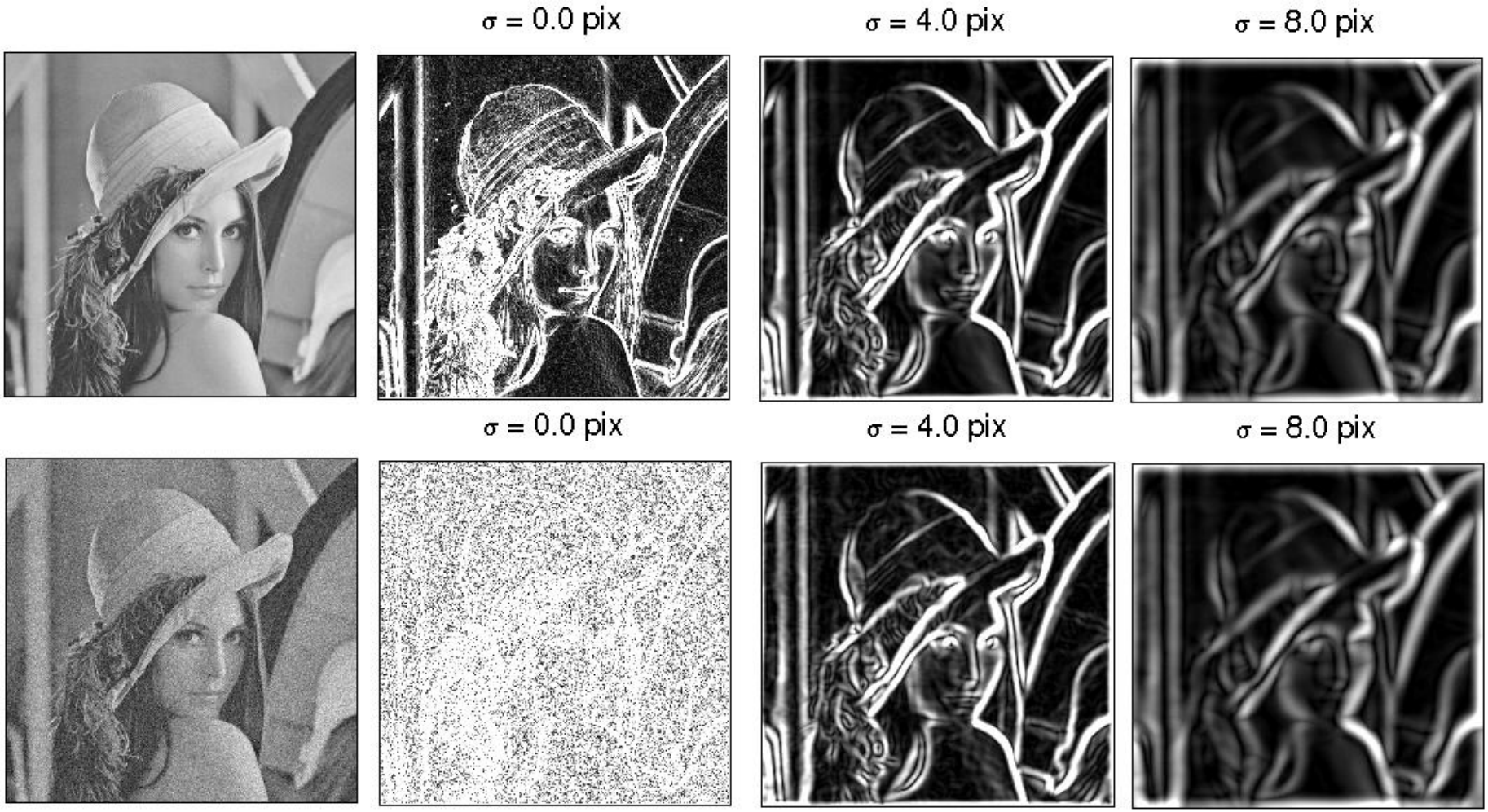
*

=

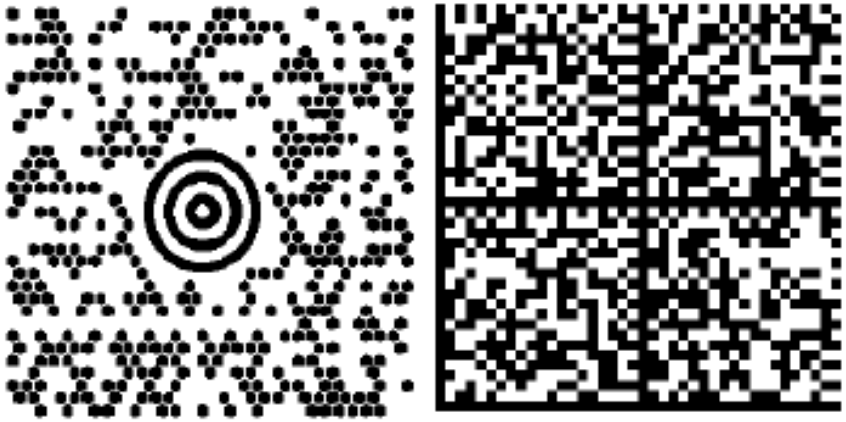
Gaussian Blur and Noise

Gaussian Blur and Noise

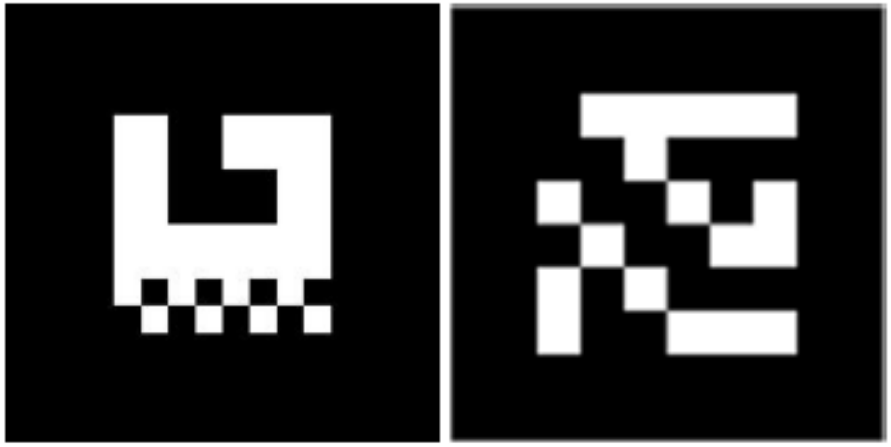
Gaussian Blur, Noise, Sobel



Fiduciary Markers/Fiducial



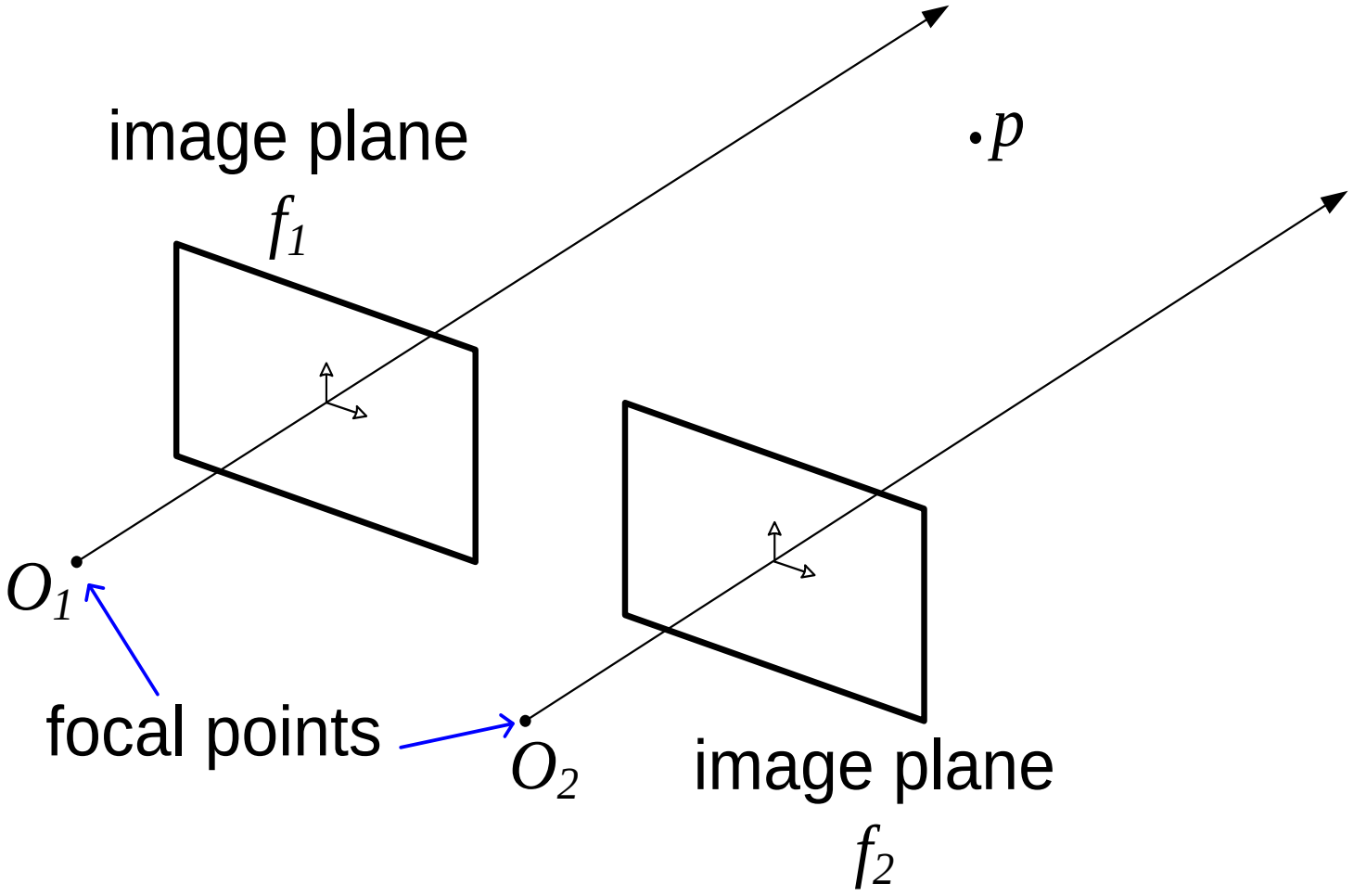
(a) MaxiCode (b) DataMatrixSymbol



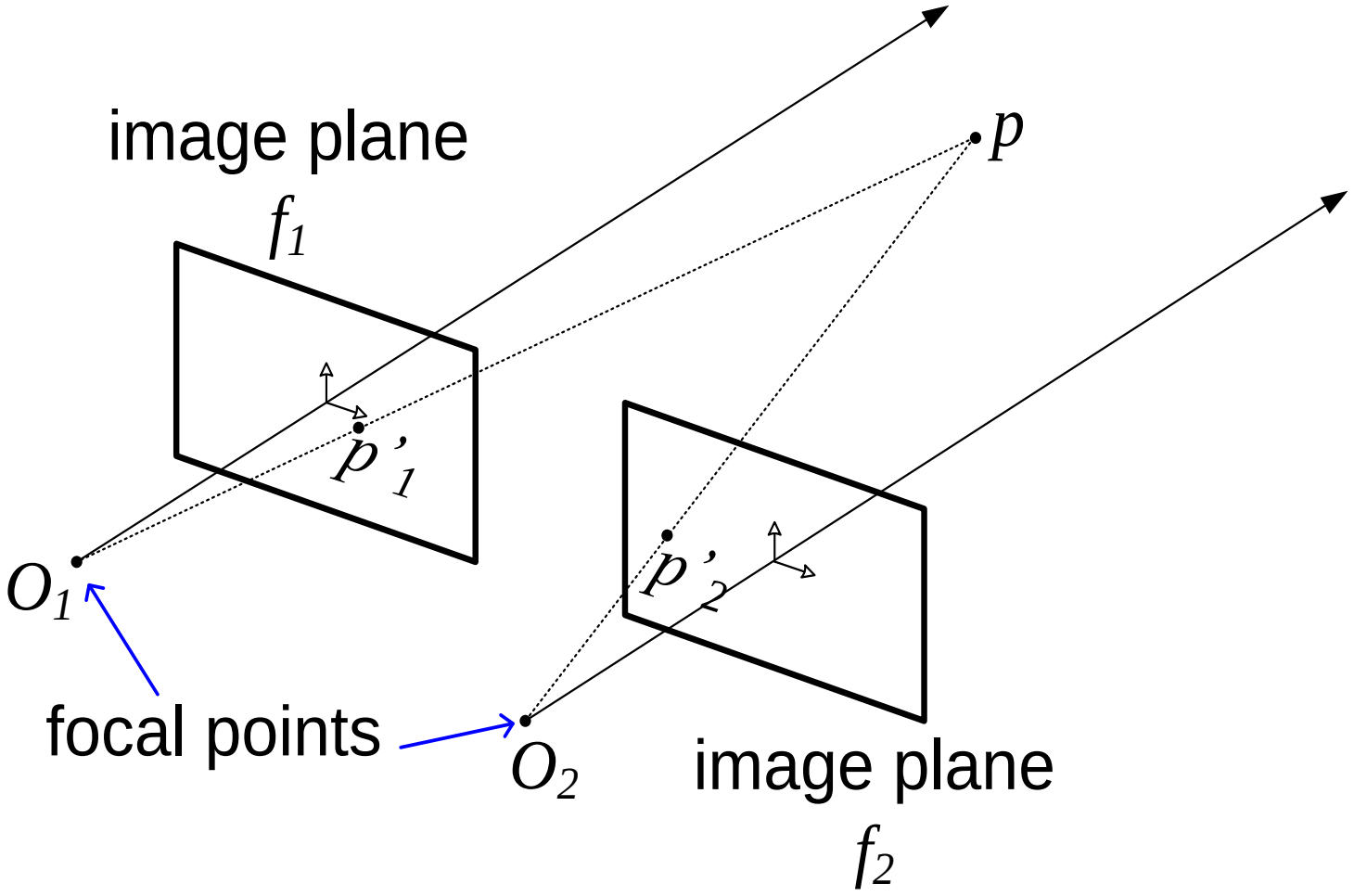
(c) ARToolkit (d) ARTag

Fourier Tag

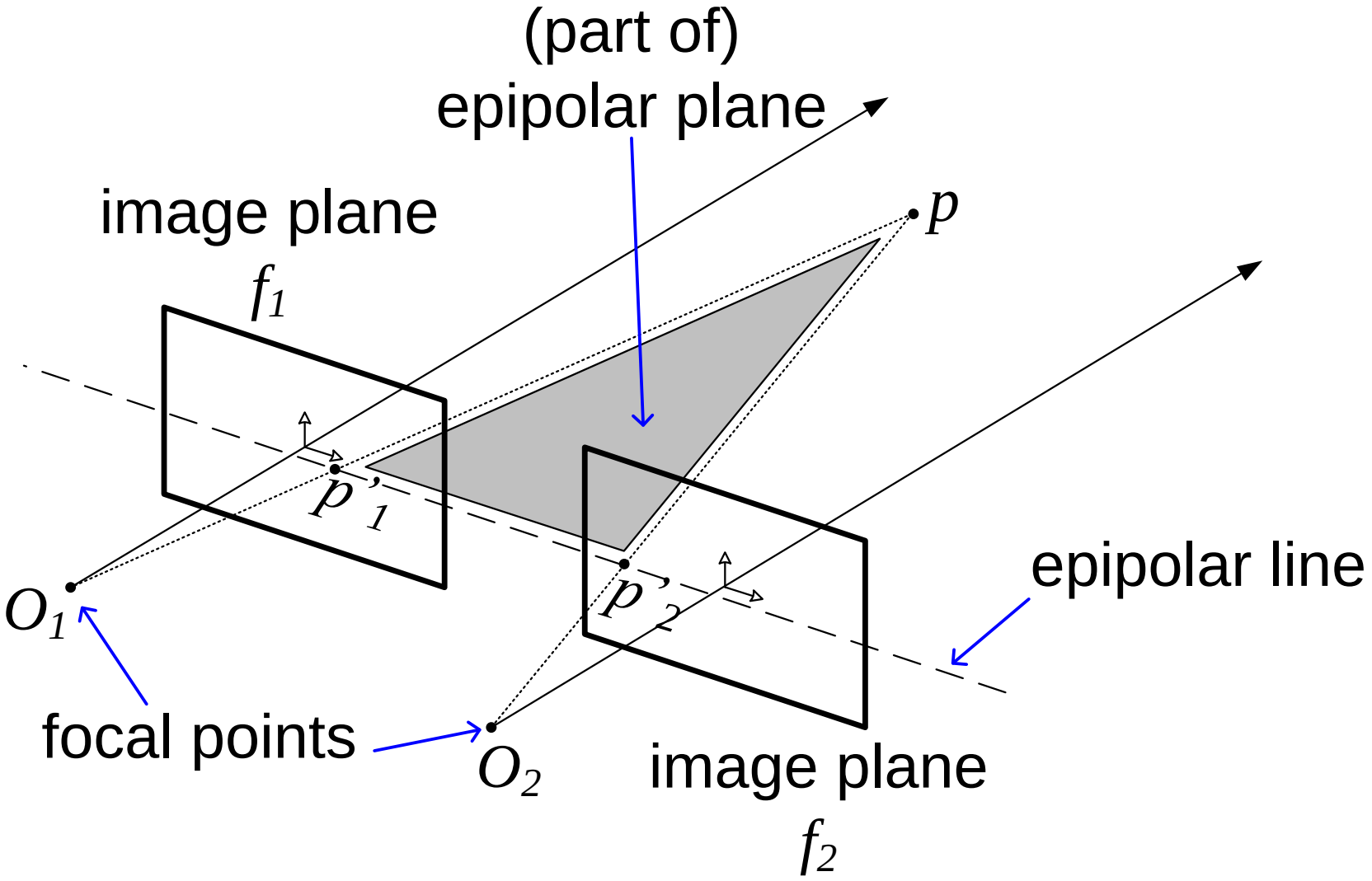
Stereo Vision: Pinhole Camera



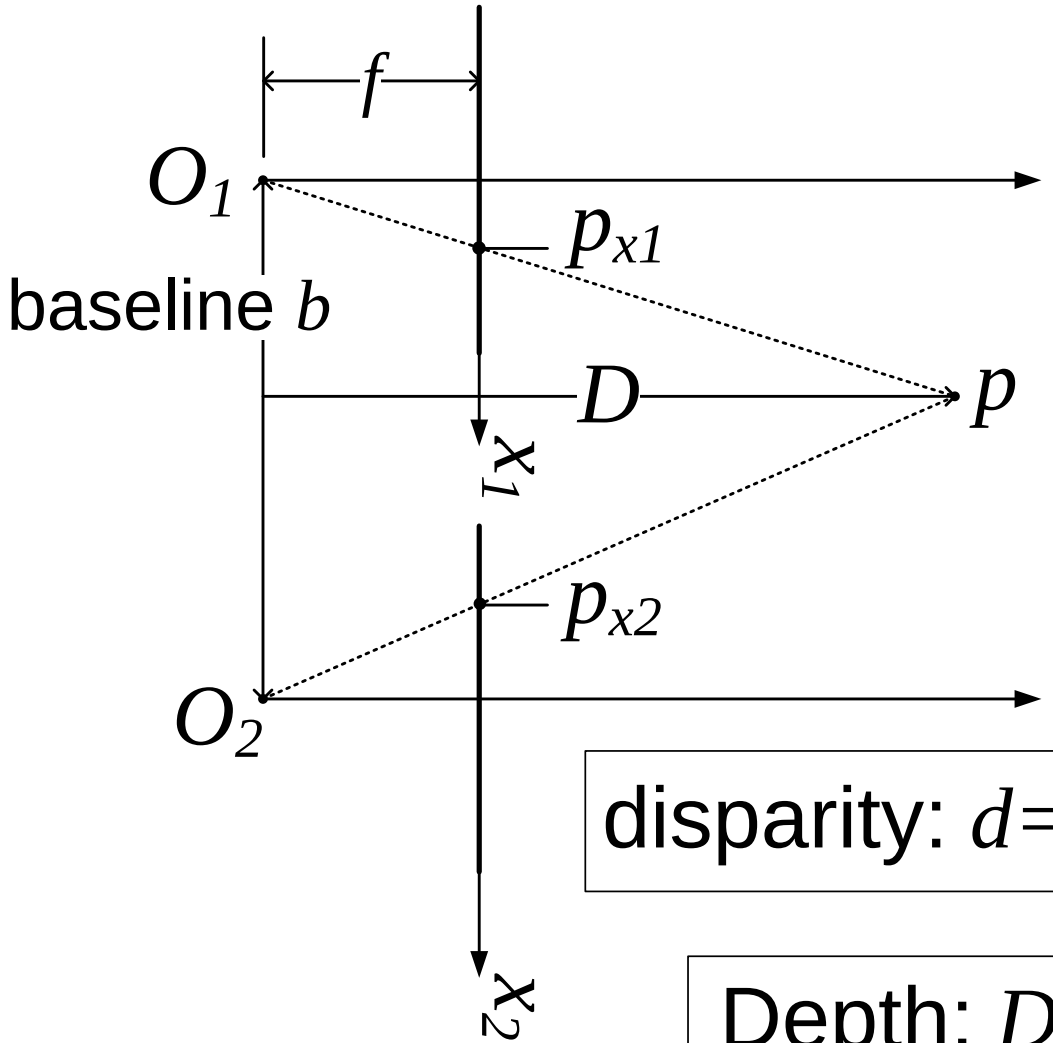
Stereo Vision: Pinhole Camera



Stereo Vision: Pinhole Camera



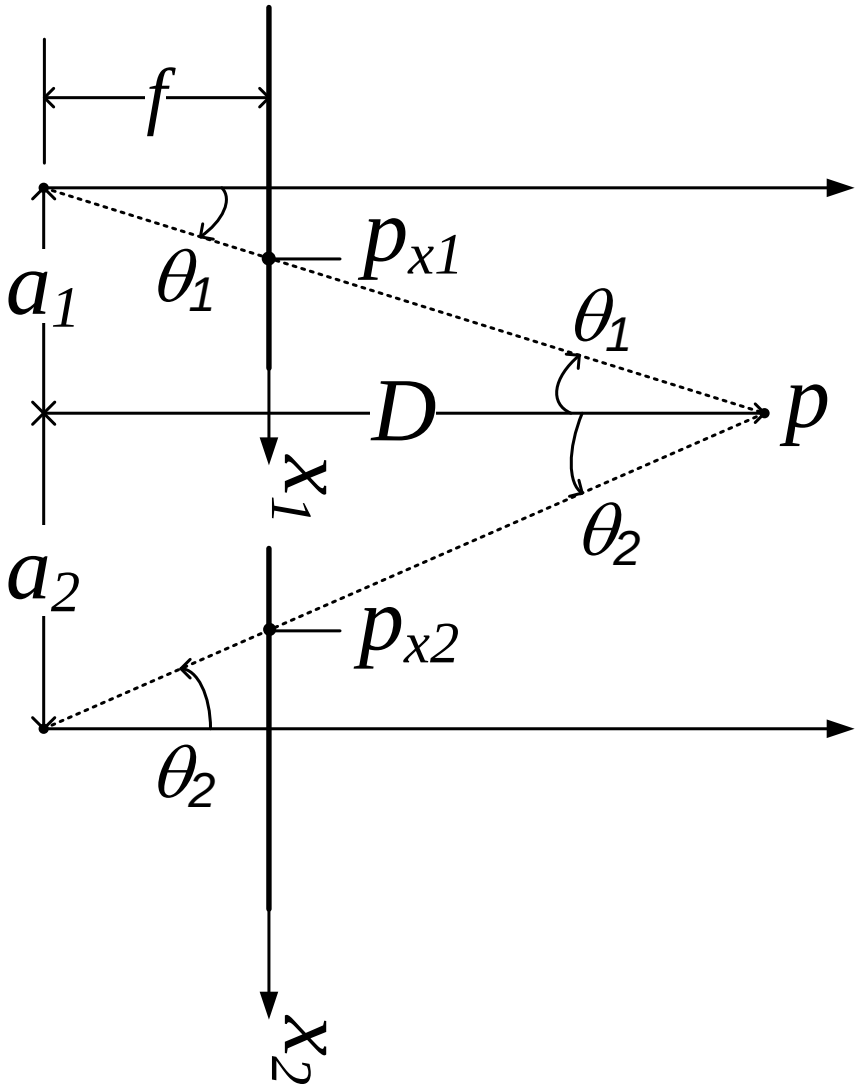
Stereo Vision: Pinhole



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

Depth: $D = fb/d$

Stereo Vision: Pinhole



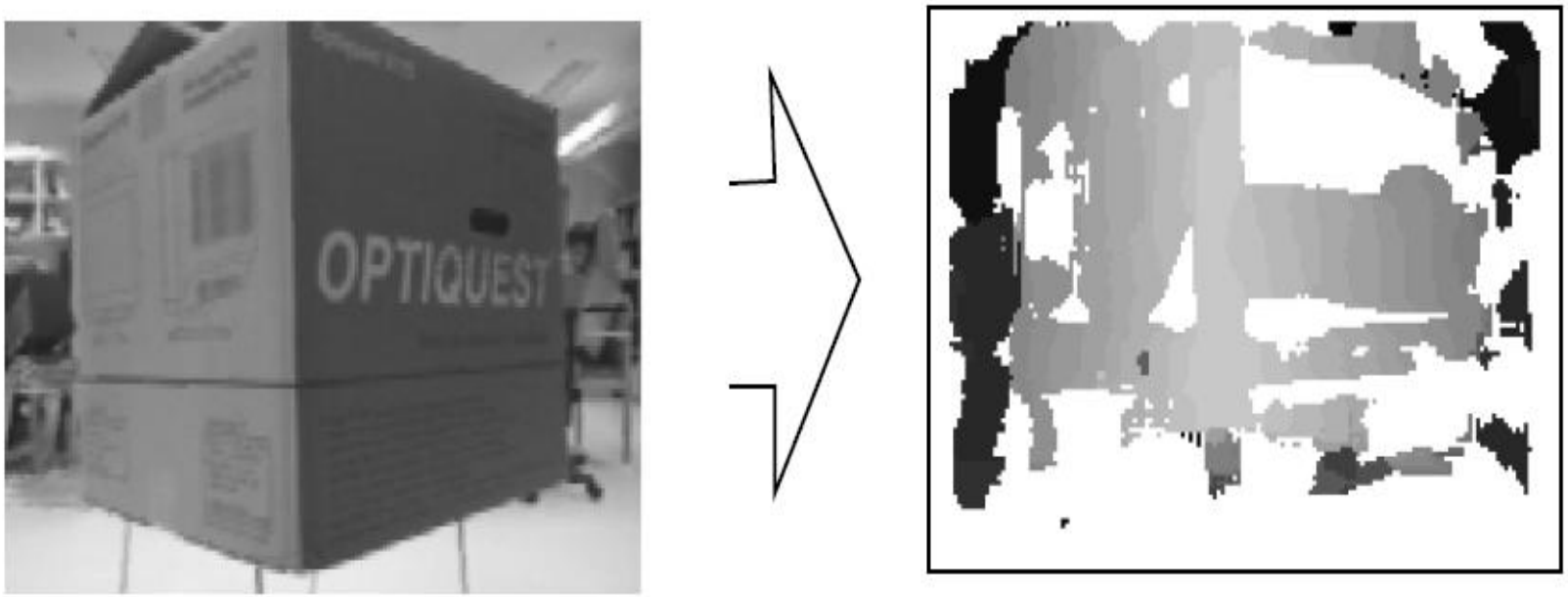
$$\frac{p_{x1}}{f} = \frac{a_1}{D}$$

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

$$a_1 + a_2 = b$$

Large Baseline

Stereo: Disparity Map

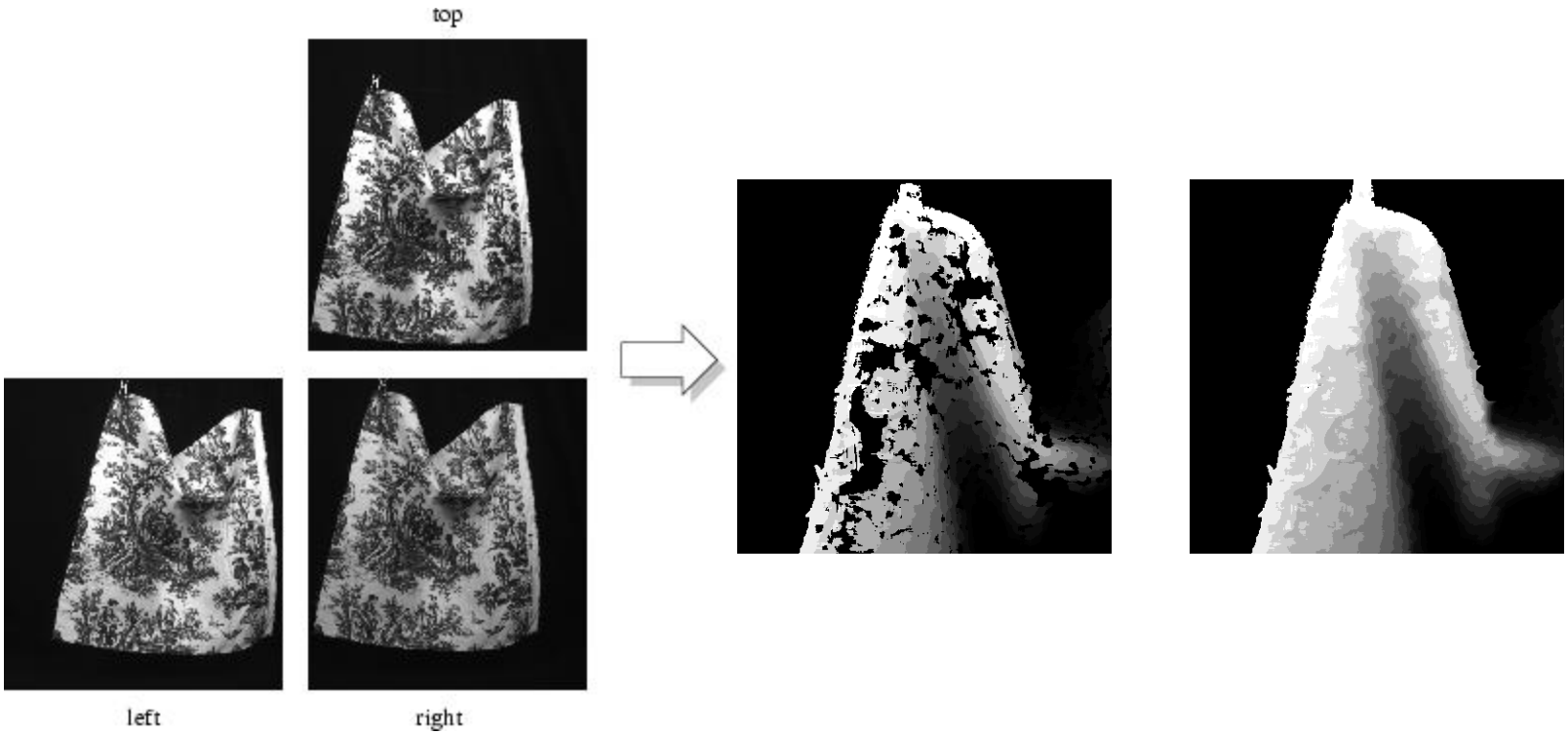


Using real-time stereo vision for mobile robot navigation

Don Murray Jim Little

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

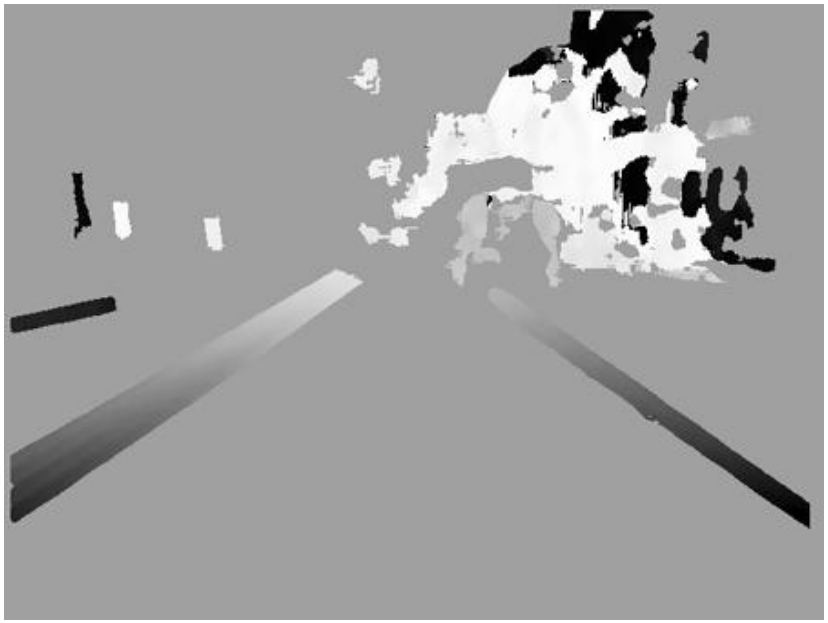
Another Example (Hole Filling)



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:

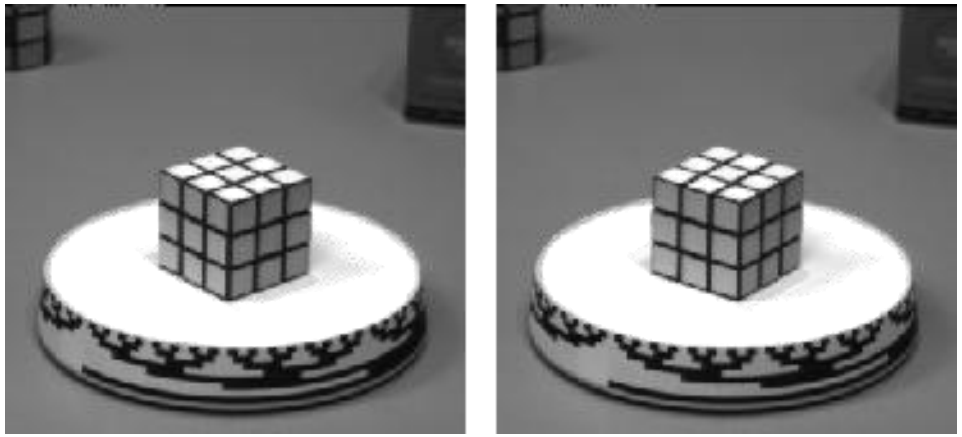
  http://vision.middlebury.edu/stereo/

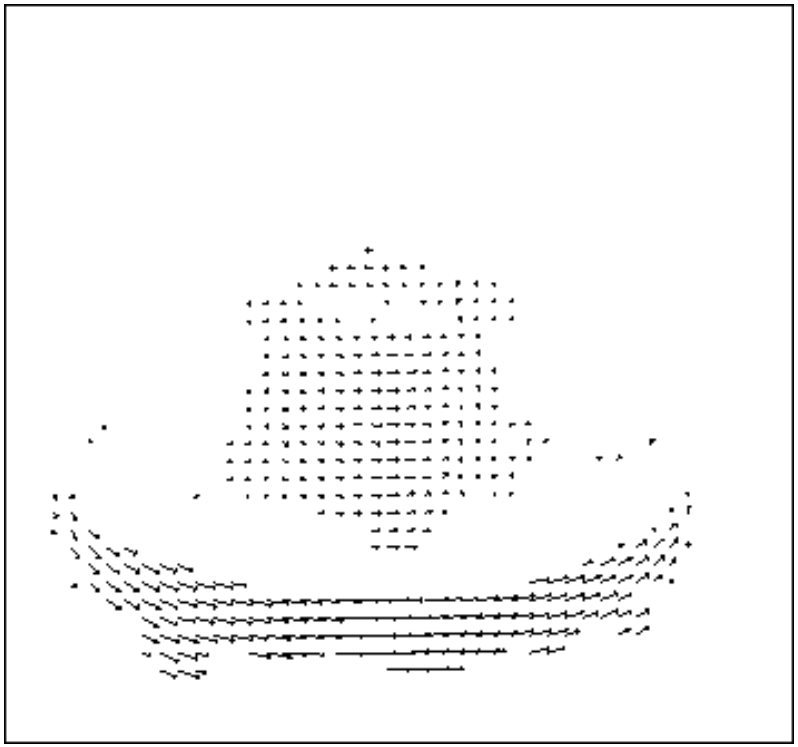
  rank 43 different algorithms.

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

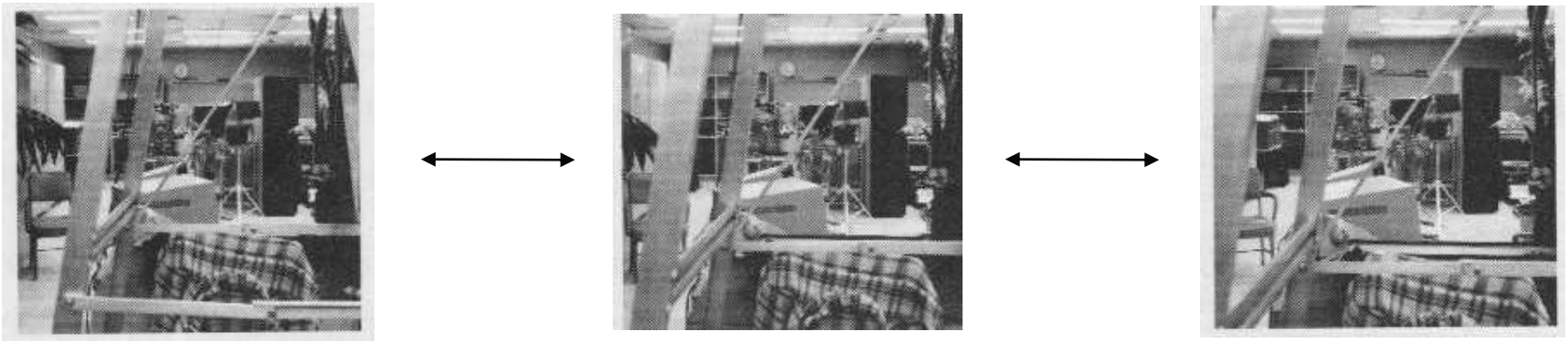




Optical flow

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

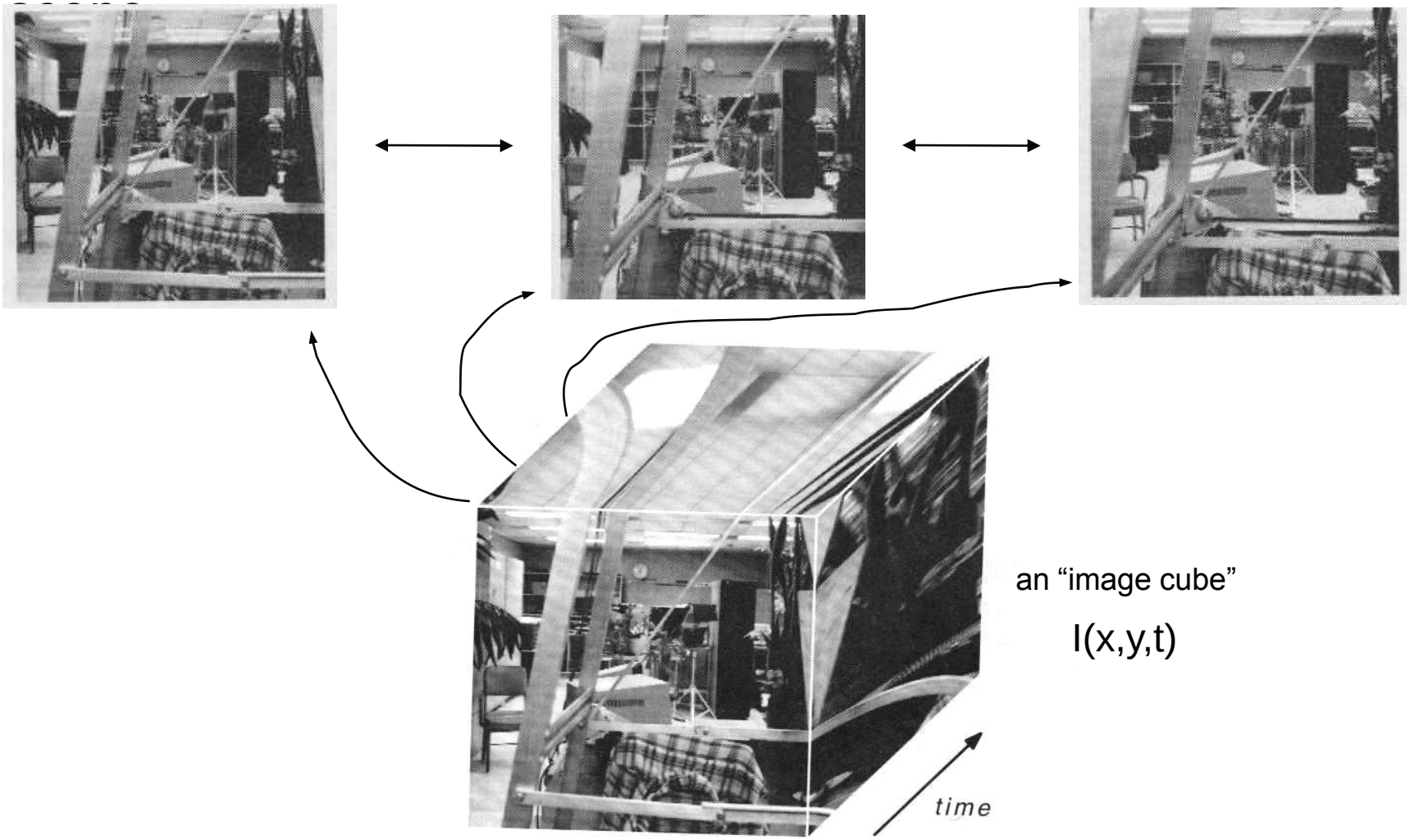
This next step might be to use the image motion to infer scene motion, robot motion or 3D layout.



time sequence of images

Optical flow

Information about *scene motion* rather than the

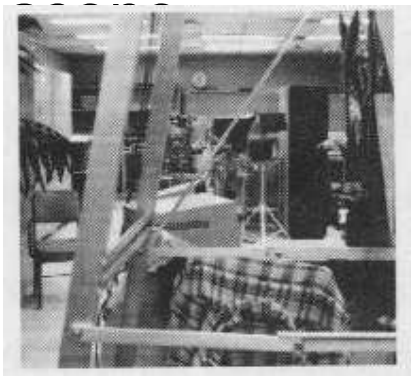


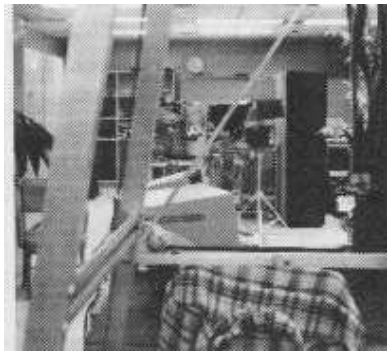
an “image cube”

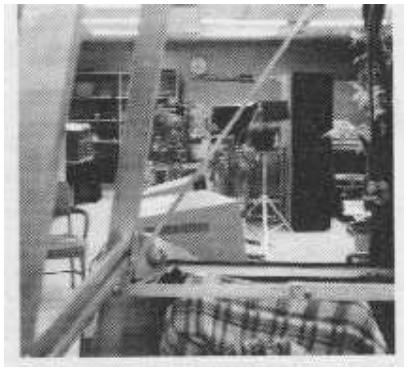
I(x,y,t)

Optical flow

Information about *scene motion* rather than the





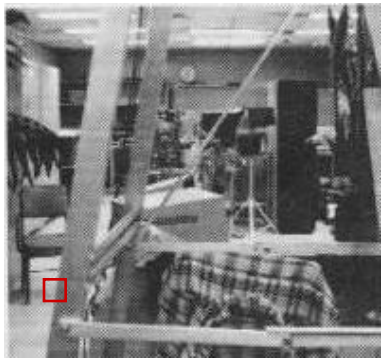


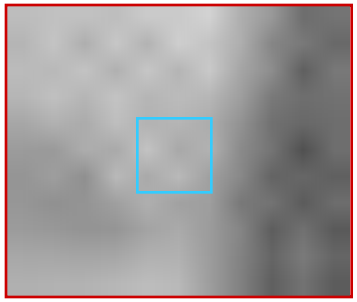
optical flow

How ?

Optical Flow

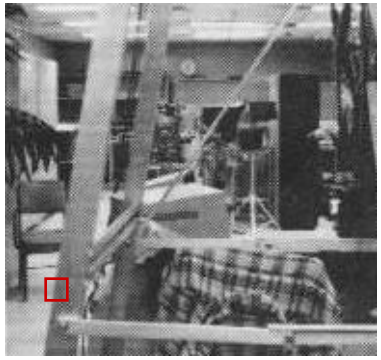
By measuring the direction that intensities are moving...

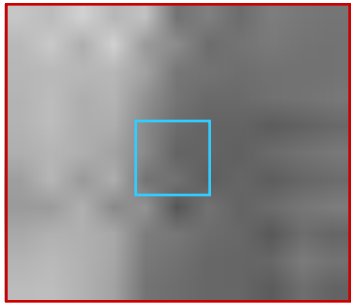




I(x,y,t)

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

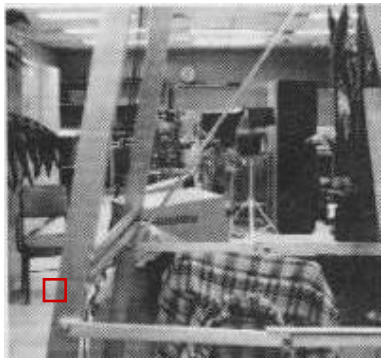
- How can we do this?
- Assume the scene itself is static.
- Find matching chunks in the images.
- An instance of *correspondence*.

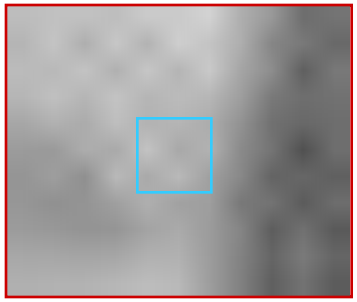
BUT

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

Optical Flow

By measuring the direction that intensities are moving...





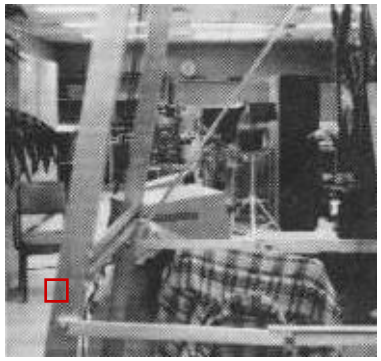
I(x,y,t)

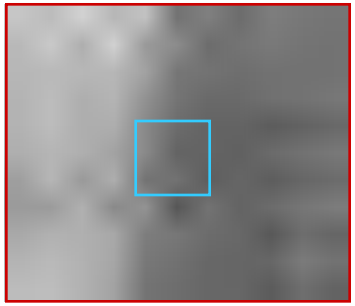
I(x,y,0)

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

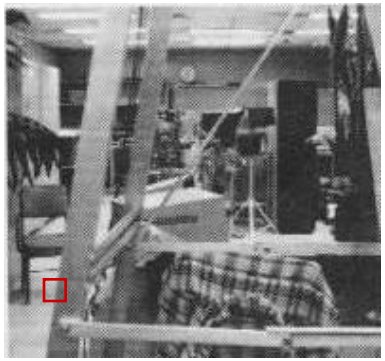
I(0,0,1)

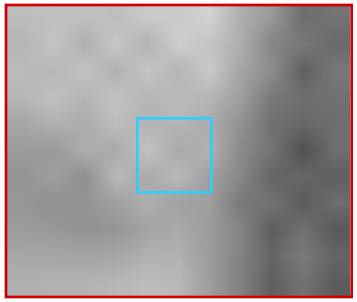
We can estimate things ...

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

Optical Flow

By measuring the direction that intensities are moving...





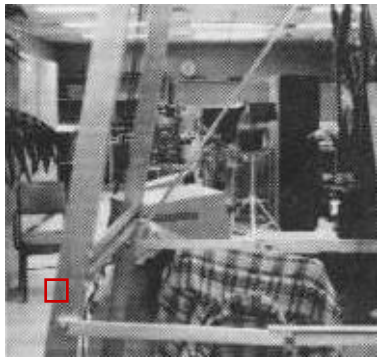
I(x,y,t)

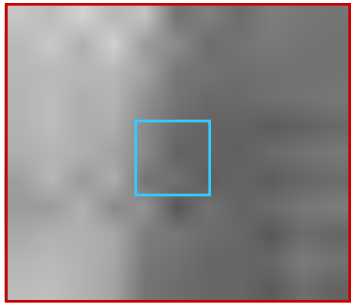
I(x,y,0)

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)

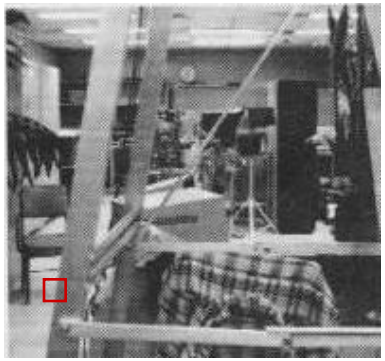
90	90	70	40	25
90	70	40	40	25
90	70	**40**	40	25
90	70	40	40	20
70	50	40	30	15

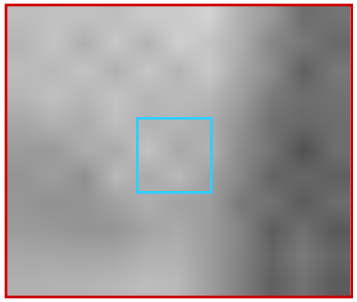
I(0,0,1)

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...

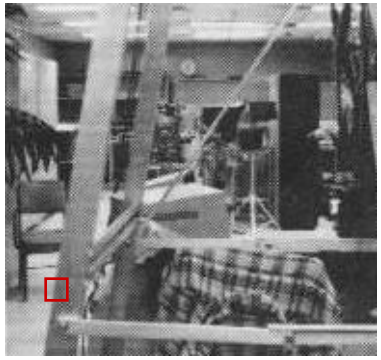


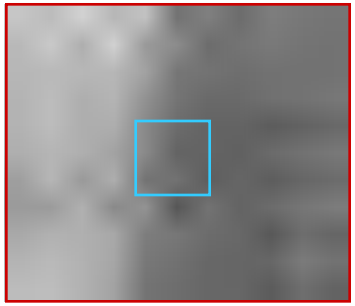


I(x,y,t)

I(x,y,0)

99 90 90 70 40	
95 90 70 40 40	
90 90 **70** 40 40	I(0,0,0)
90 90 70 40 **40**	I(2,-1,0)
90 70 50 40 30	





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

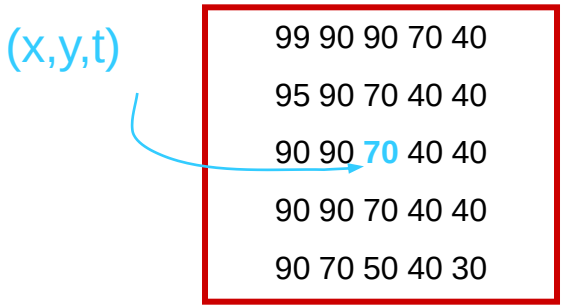
so...

Measuring Optical Flow

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

Simplest assumption (constant brightness constraint):

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



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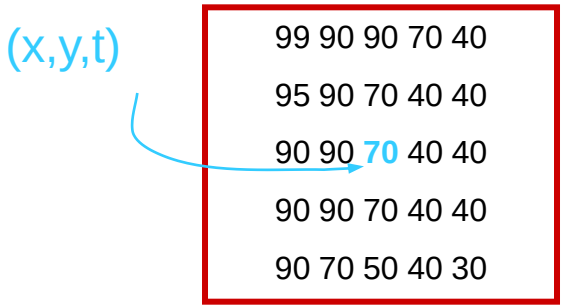
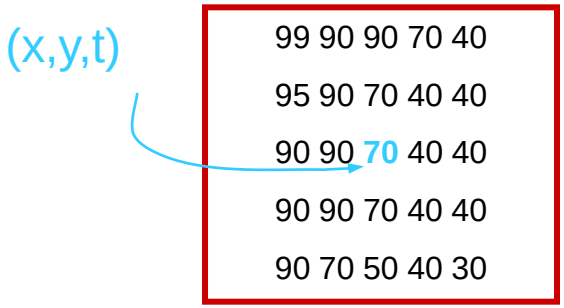


Reminder: $f(x + dx) = f(x) + f'(x)\,dx + f''(x)\,dx^2/2 + \ldots$

Measuring Optical Flow

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



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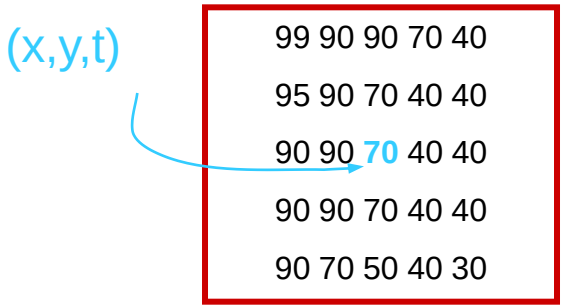
Reminder: $f(x + dx) = f(x) + f'(x)\,dx + f''(x)\,dx^2/2 + \ldots$

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

Measuring Optical Flow

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



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

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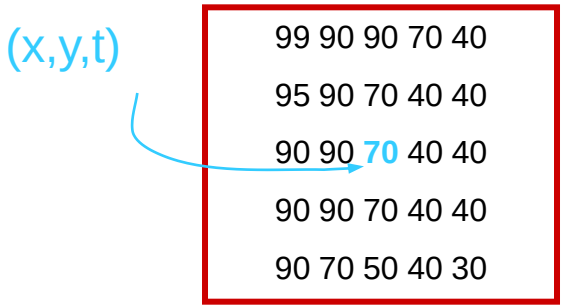
$$I(x,y,t) = I(x,y,t) + I_x\,dx + I_y\,dy + I_t\,dt + \text{2nd deriv. + higher}$$

ignore these terms

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

Measuring Optical Flow

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



Simplest assumption (constant brightness constraint):

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

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

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

ignore these terms

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

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

intensity-flow equation

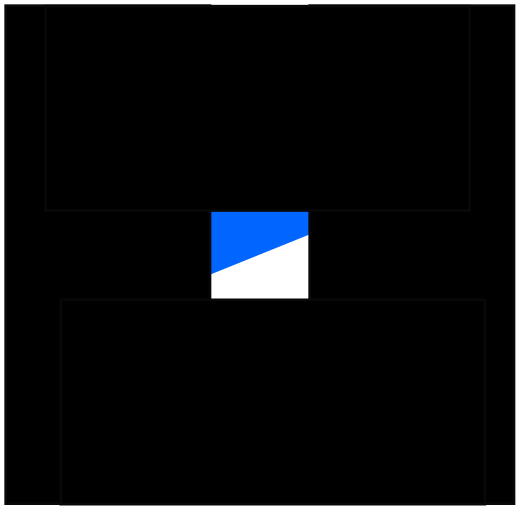
good and bad...

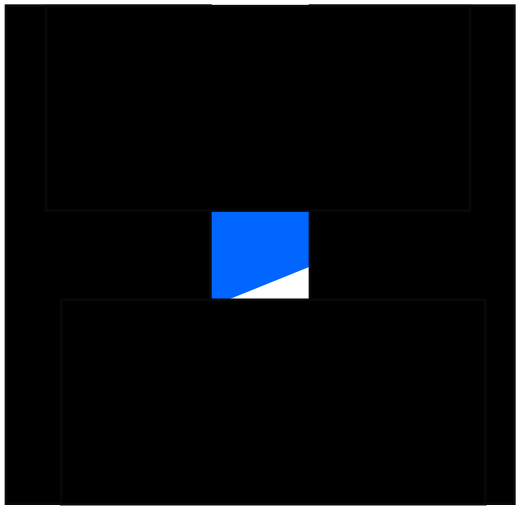
The “aperture” problem

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

- 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...





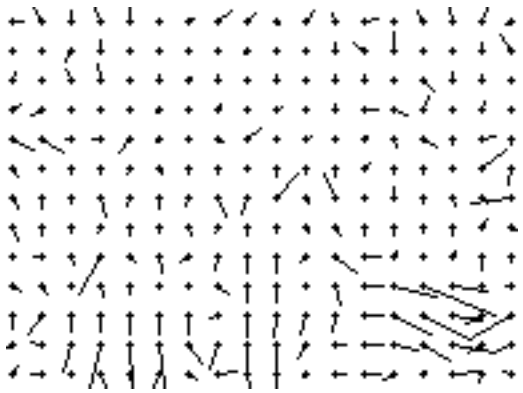
The aperture problem

⟶ 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.

SIFT


BASSONGINI
Crisp Almond Cookies
Biscotti di Pasta
alla Mandorla
NATURALE
Peso Netto 250 g e
NET WT 8.8 OZ

Optical Flow Application

- Visual Odometry
  - Wheel slip detection on future Mars Rovers

Image Downsampling