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.

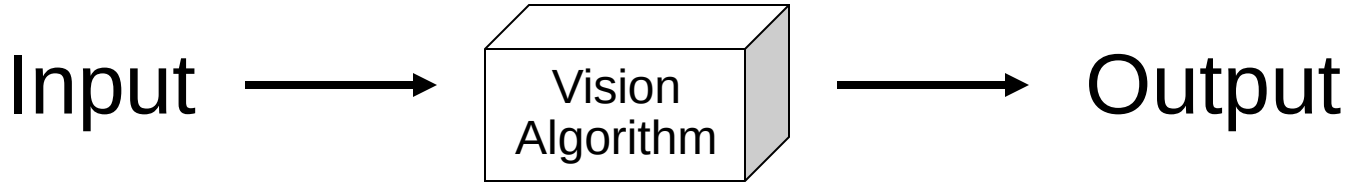
So, what's the problem?

- 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
253 197 190 233 251 054 143 209 196 014 254 254 253 228 251
252 228 176 218 251 070 176 219 200 024 250 255 255 254 195
248 244 163 227 252 091 071 185 079 021 252 251 255 254 138
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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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224 216 162 189 200 254 217 198 209 216 206 226 186 228 219
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222 224 197 146 201 204 108 220 201 210 196 223 200 233 218
226 232 177 184 175 230 214 199 146 255 134 225 205 216 181
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043 144 165 159 154 171 224 191 047 030 171 165 175 164 163
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013 049 076 059 032 028 174 197 182 060 021 021 121 101 062
013 059 111 072 020 078 200 211 182 061 069 059 043 086 106
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025 161 174 172 167 049 200 193 112 028 120 169 173 177 173

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254 176 211 255 250 126 116 086 070 064 253 252 233 239 253
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253 219 190 239 248 119 061 095 065 011 254 254 253 231 255
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255 221 179 255 227 099 058 029 034 052 240 249 243 232 253
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
223 217 120 033 059 071 042 044 013 155 060 070 076 213 219
224 216 030 082 075 139 076 083 099 114 076 133 057 228 219
215 222 033 092 067 063 031 023 070 025 125 055 136 224 226
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107 054 027 044 020 035 062 039 115 048 051 046 005 051 117
098 006 045 033 030 027 036 054 025 072 112 044 029 060 115

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
254	170	204	255	248	122	153	135	111	081	252	253	233	232	250
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253	210	190	239	250	089	092	149	128	013	254	254	253	229	255
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
253	255	171	254	253	142	037	132	006	017	253	253	255	254	201
253	250	170	255	253	139	134	127	156	078	255	253	253	254	237
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252	244	140	215	245	125	055	043	081	077	252	234	253	253	253
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254	234	167	212	217	110	070	049	098	074	244	246	239	207	254
255	219	170	238	253	113	130	109	063	075	243	235	233	252	252
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
221	215	194	100	154	071	008	031	097	010	093	098	148	229	216
223	217	132	046	072	076	056	048	013	182	073	076	083	215	219
224	216	041	102	090	162	079	111	118	164	083	170	065	221	219
215	222	046	111	077	075	060	046	069	032	179	068	157	224	226
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226	232	118	109	041	165	130	105	097	175	078	081	067	064	174
253	254	079	072	116	089	020	068	103	074	031	130	106	052	161
047	034	090	045	145	027	135	109	082	082	048	113	087	061	157
193	192	057	038	051	092	018	062	110	052	060	084	066	071	154
191	192	043	153	052	030	078	061	062	054	046	049	054	078	158
184	181	066	019	043	038	046	083	057	050	145	048	035	087	158
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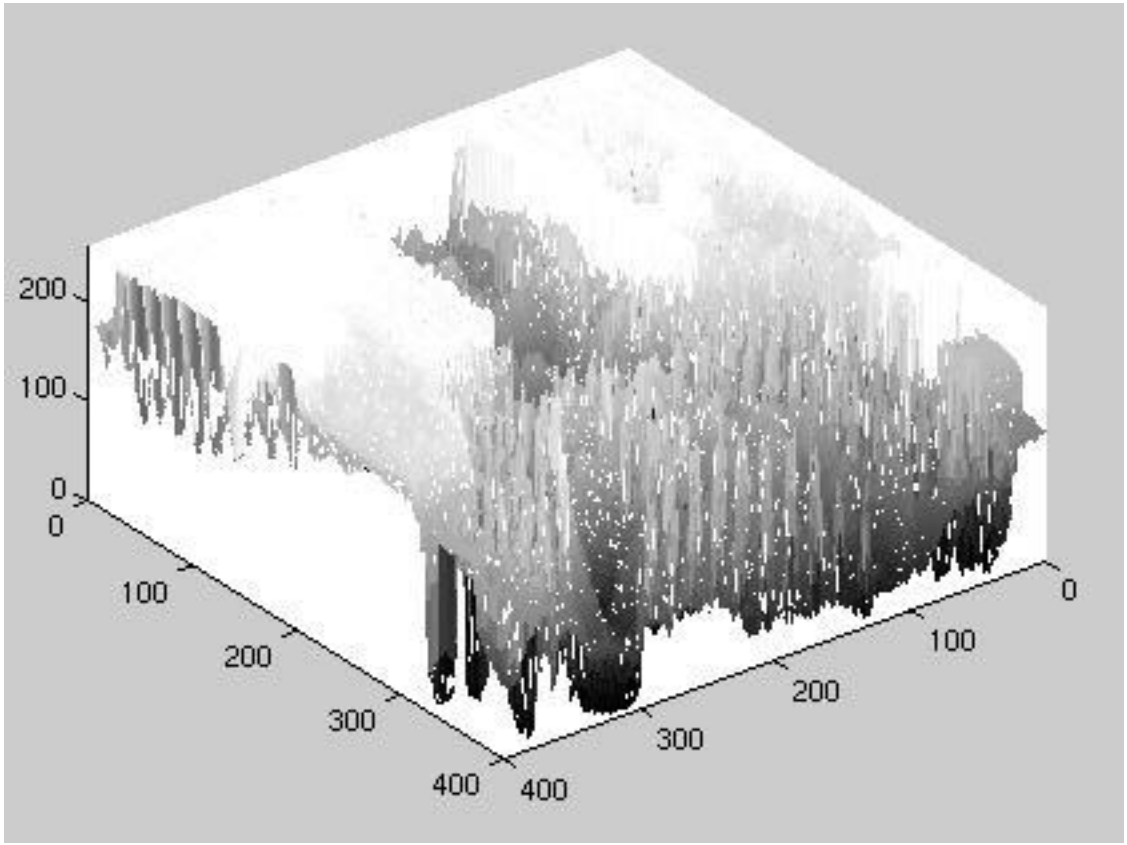

Looking at vision

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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
255 172 201 255 249 123 092 040 094 106 255 253 239 150 254
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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
254 170 204 255 248 122 153 135 111 081 252 253 233 232 250
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255 197 192 255 248 133 024 027 076 032 250 255 255 181 255
253 210 190 239 250 089 092 149 128 013 254 254 253 229 255
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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
047 125 130 130 122 121 117 142 131 133 134 141 149 144 135
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043 144 165 159 154 171 224 191 047 030 171 165 175 164 163
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018 008 009 019 023 093 109 128 063 052 031 010 012 009 006
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014 007 008 011 007 012 010 009 007 008 007 005 005 007 003
020 011 015 019 013 017 017 013 019 013 012 013 011 009 005
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...

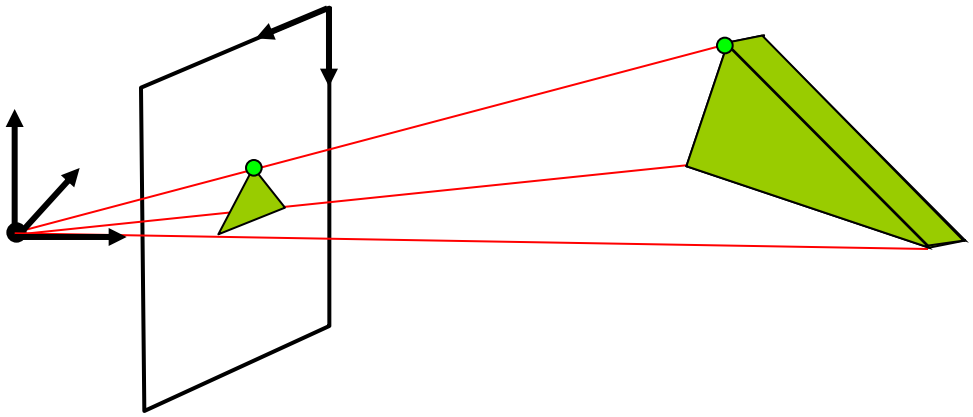
squeezes away one dimension

Ill-posed

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

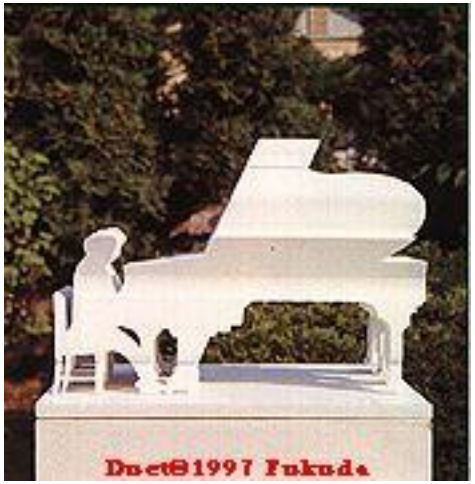
The vision problem in general...

- 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



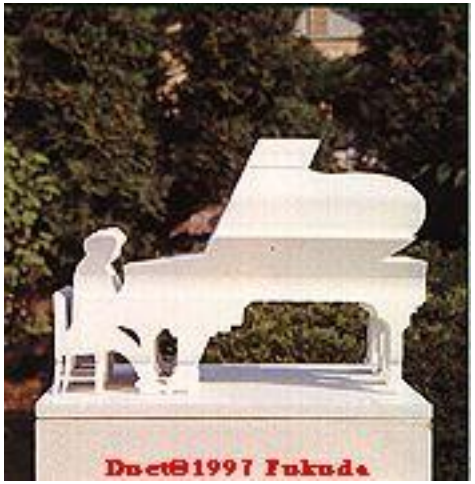
Ill-posed

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



Ill-posed

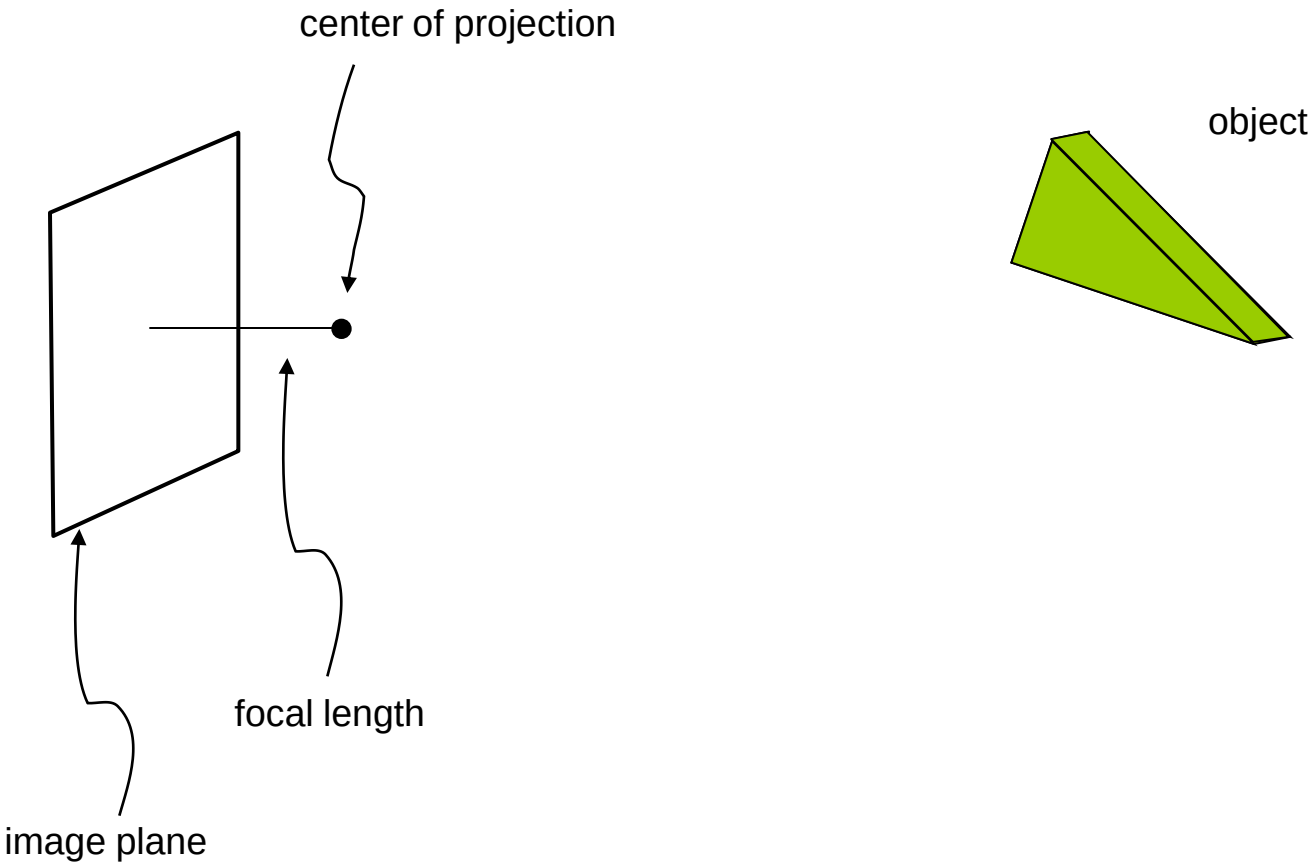
• In trying to extract 3d structure from 2d images, vision is **an *ill-posed* problem**.



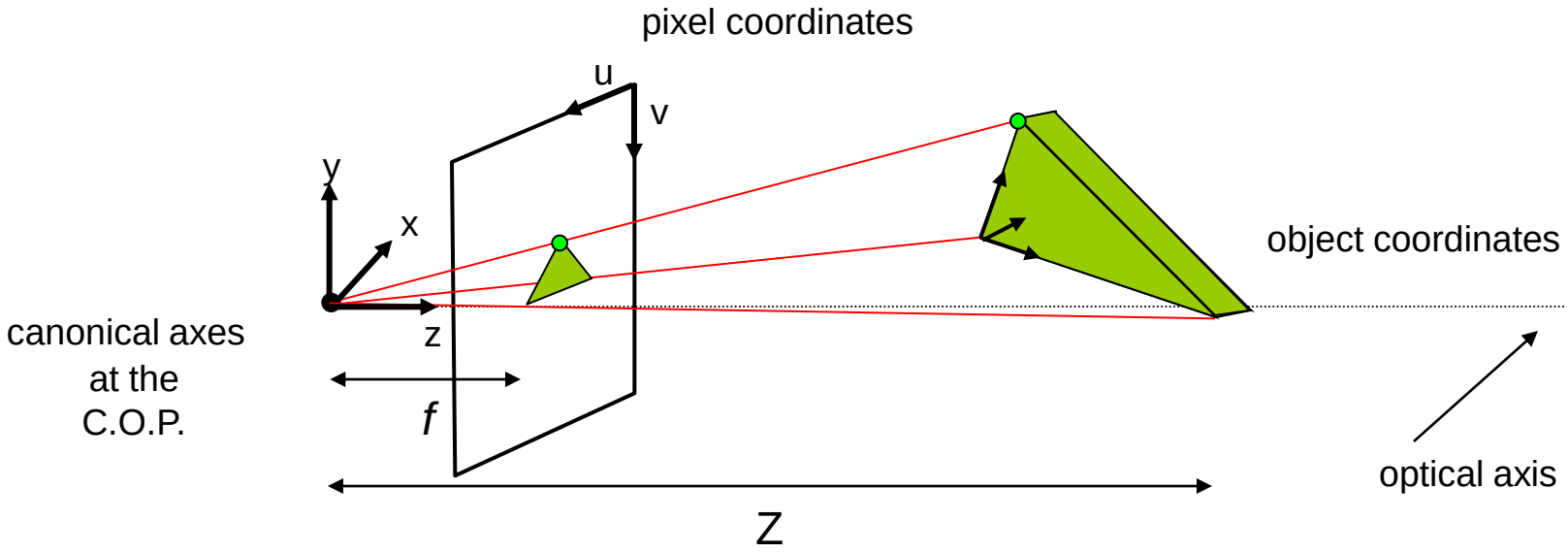
- An image isn’t enough to disambiguate the many possible 3d worlds that could have produced it.

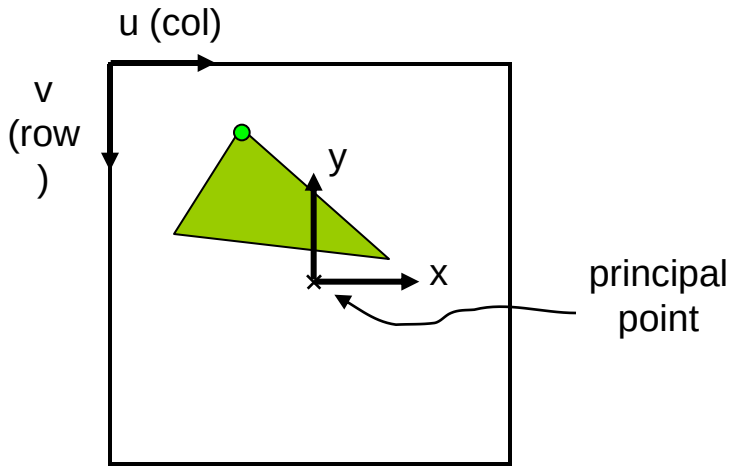
Camera Geometry

3d → 2d transformation: perspective projection



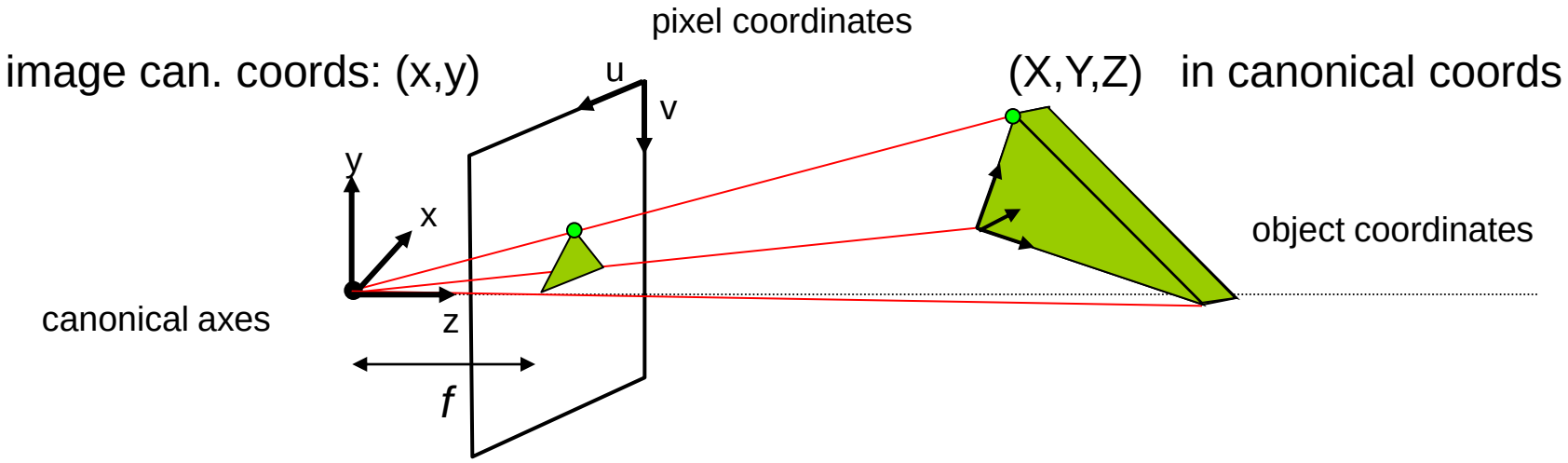
Coordinate Systems



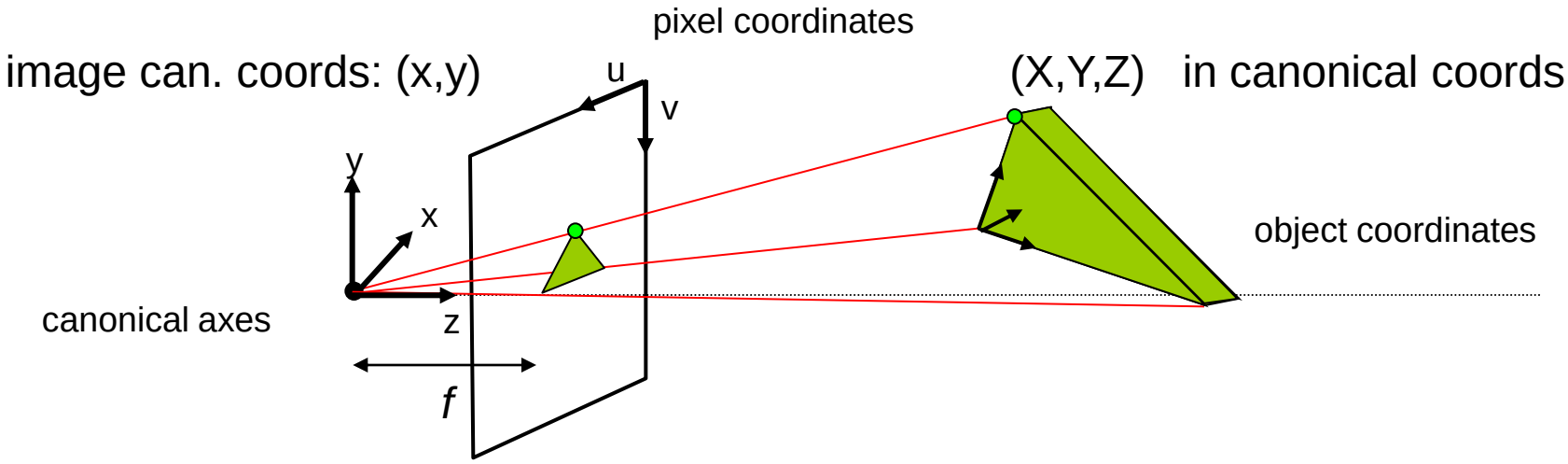


Add coordinate systems in order to describe feature points...

Coordinate Systems



From 3d to 2d



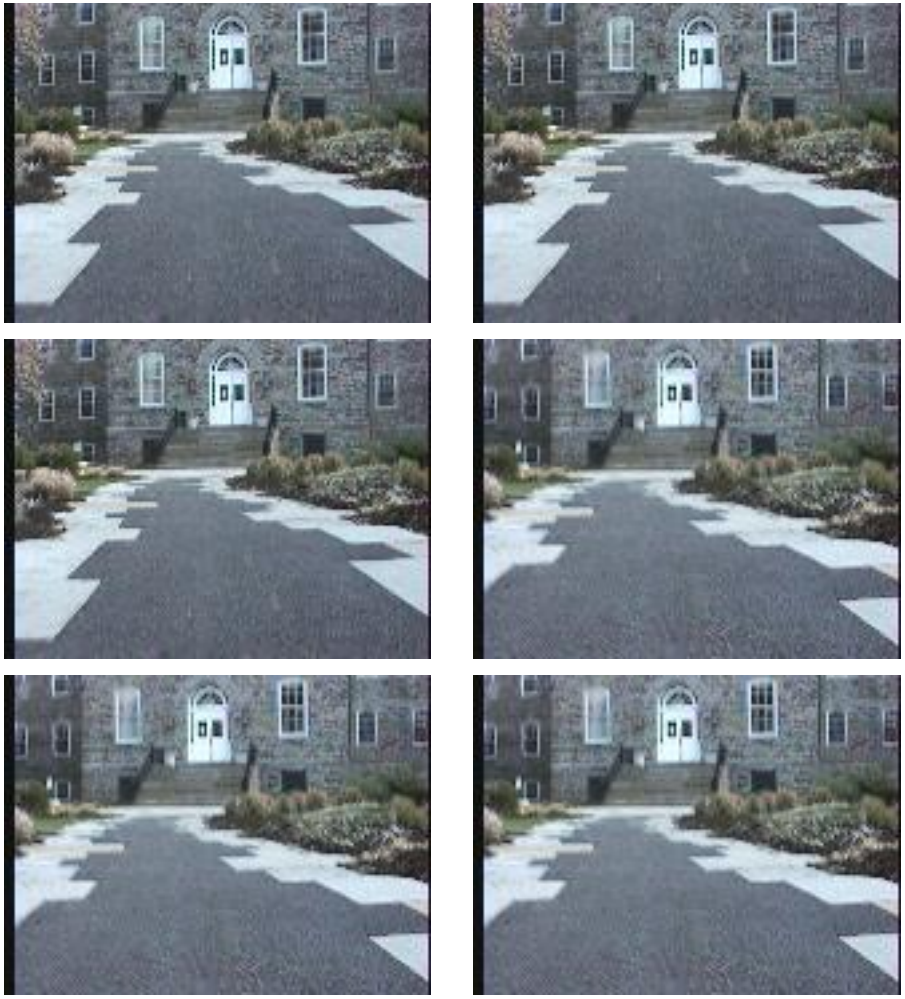
$$x = \frac{f\,X}{Z} \qquad y = \frac{f\,Y}{Z}$$

a nonlinear transformation

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

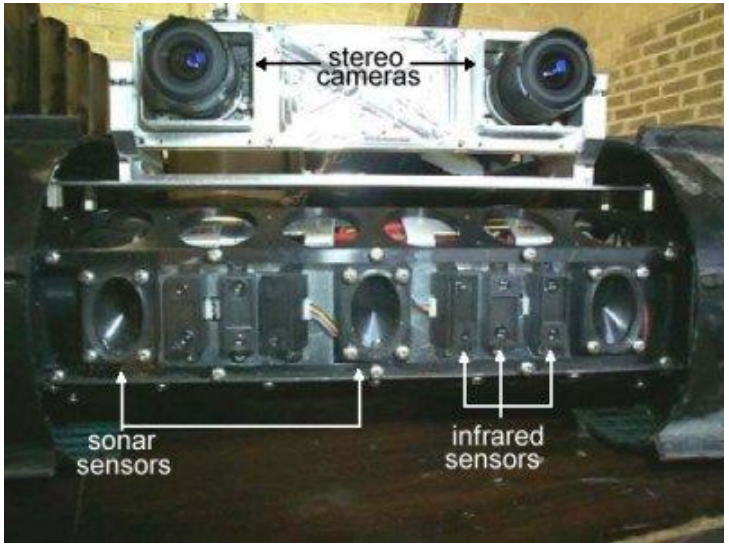
A Vision “solution”

- 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

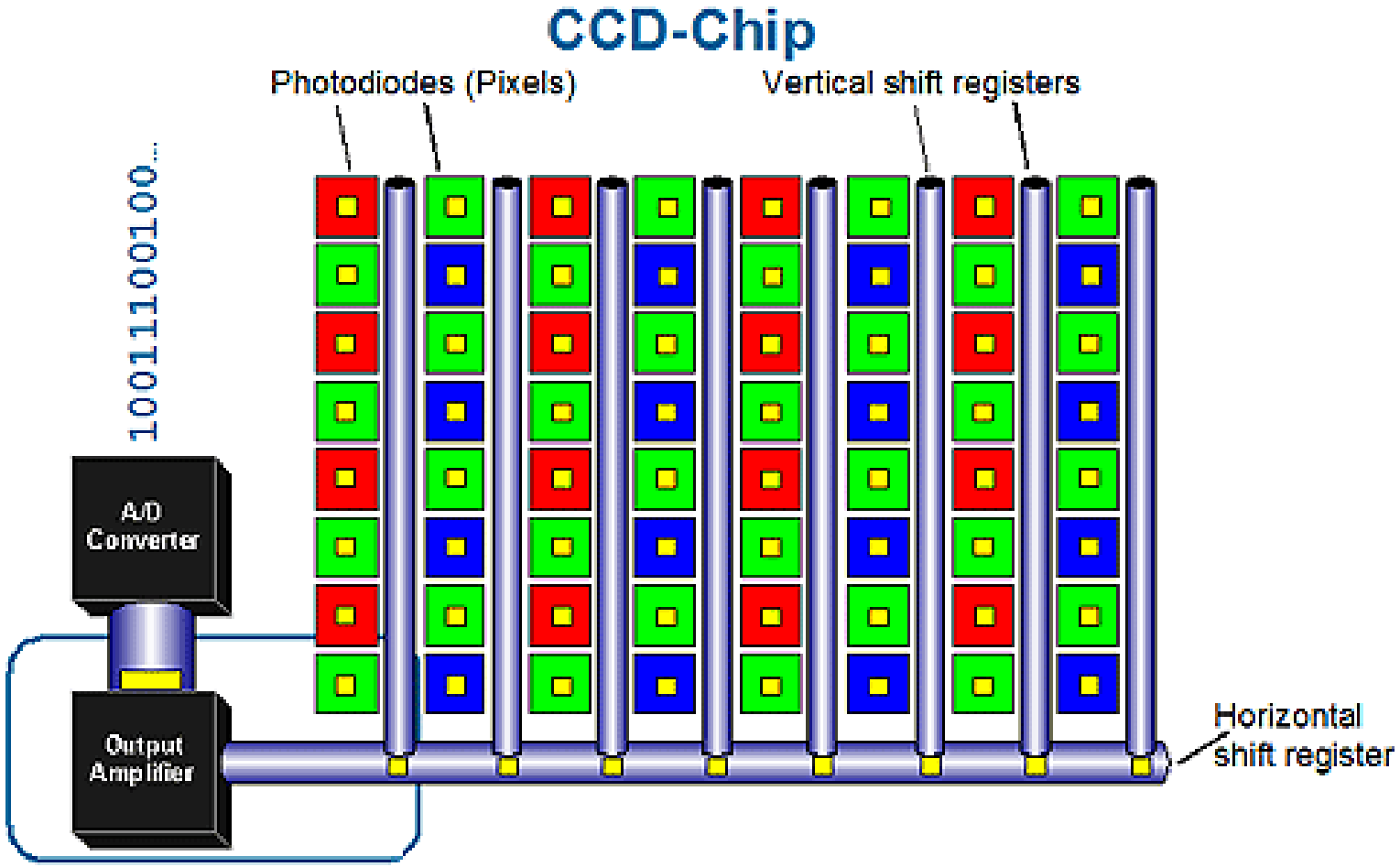
- → 3d reconstruction
- → Visual “servoing”

speaking of servoing...

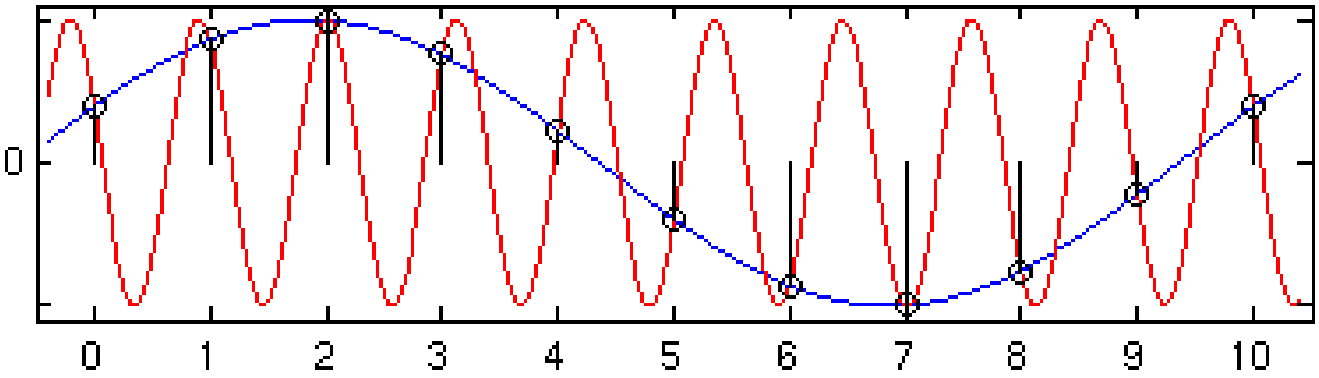
Details

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

CCD (Charge-Coupled Device)

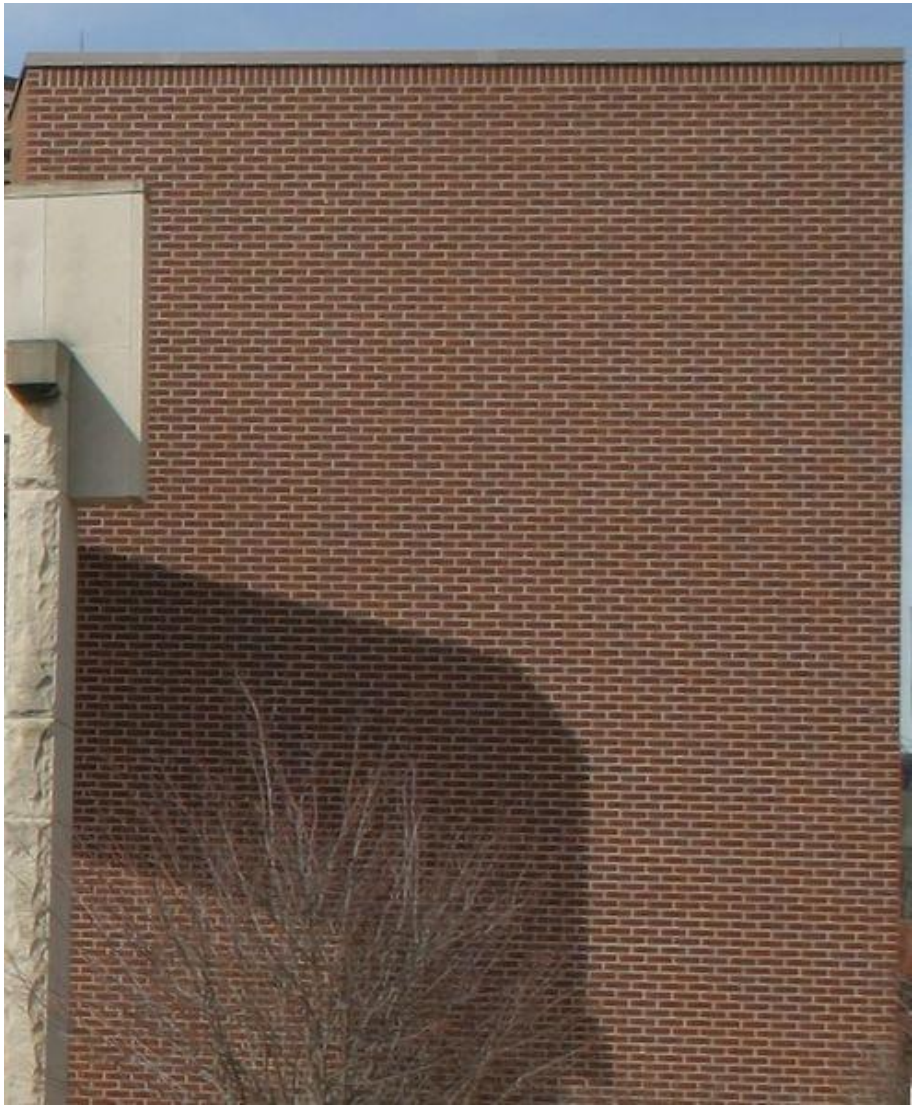


Aliasing.



- 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.”

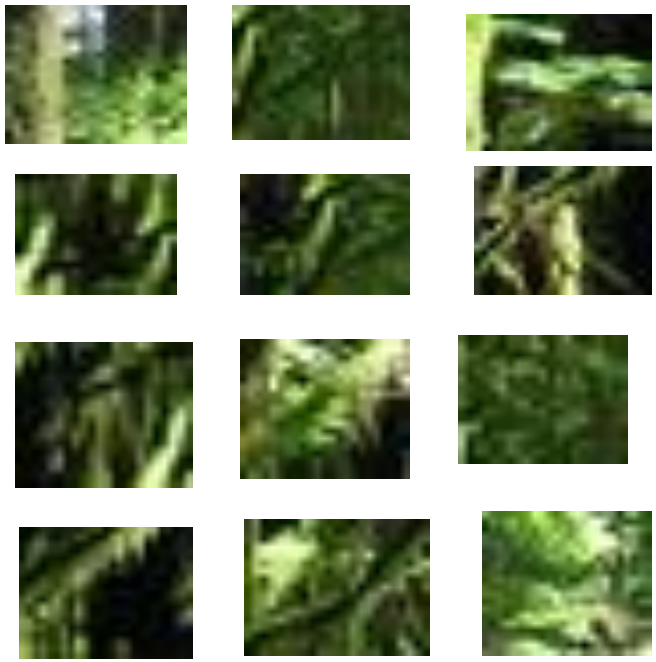
Correspondence Problem

Correspondence

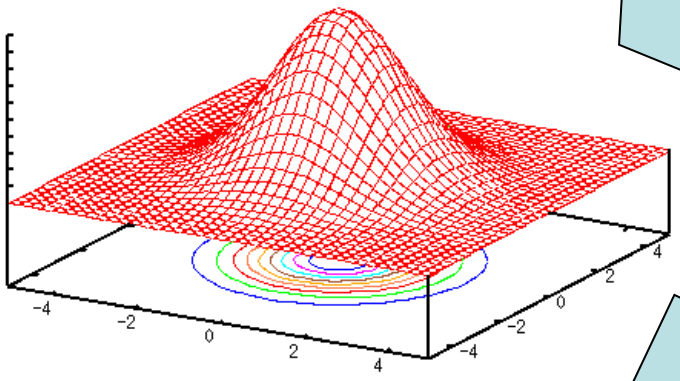
From I_1

From I_2

—?→



Gaussian Blur



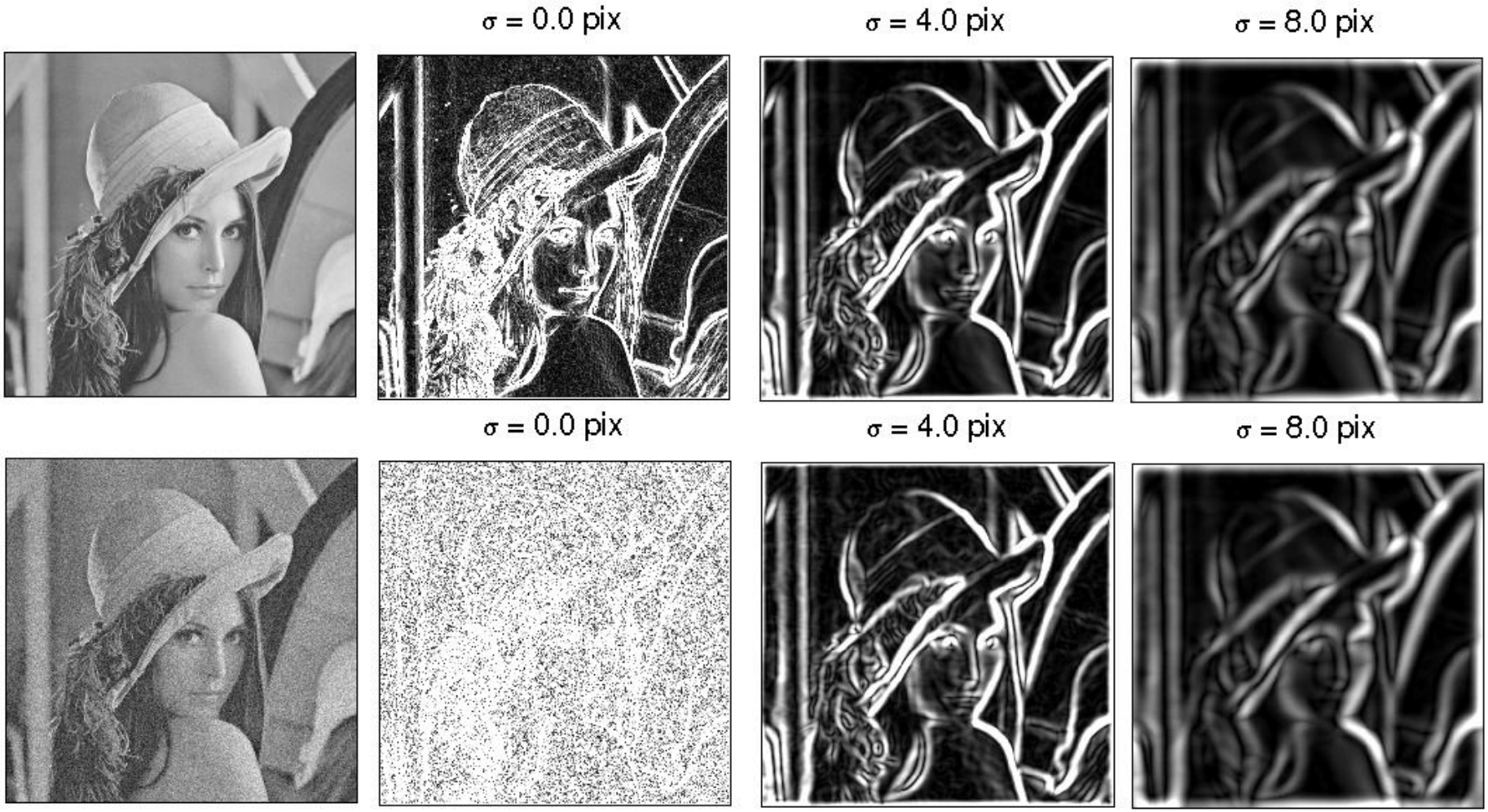
*

=

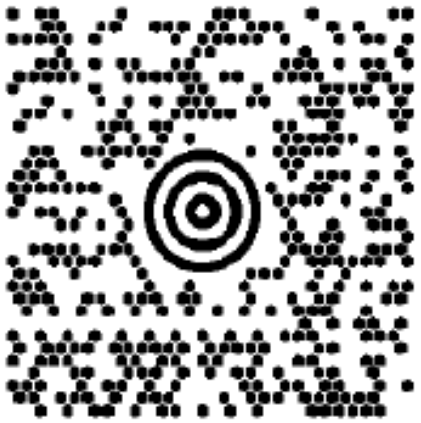
Gaussian Blur and Noise

Gaussian Blur and Noise

Gaussian Blur, Noise, Sobel



Fiduciary Markers/Fiducial



(a) MaxiCode

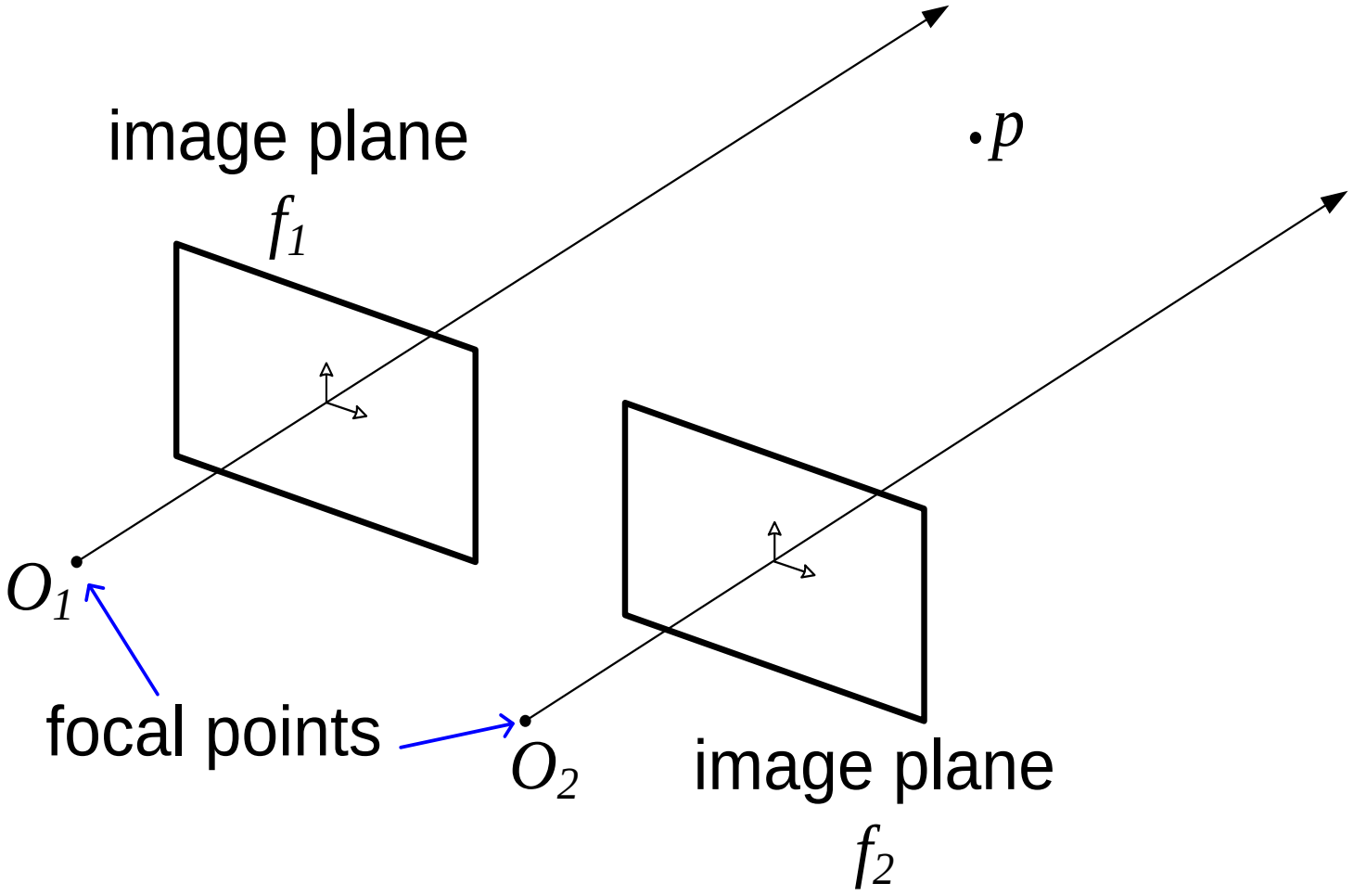
(b) DataMatrixSymbol

(c) ARToolkit

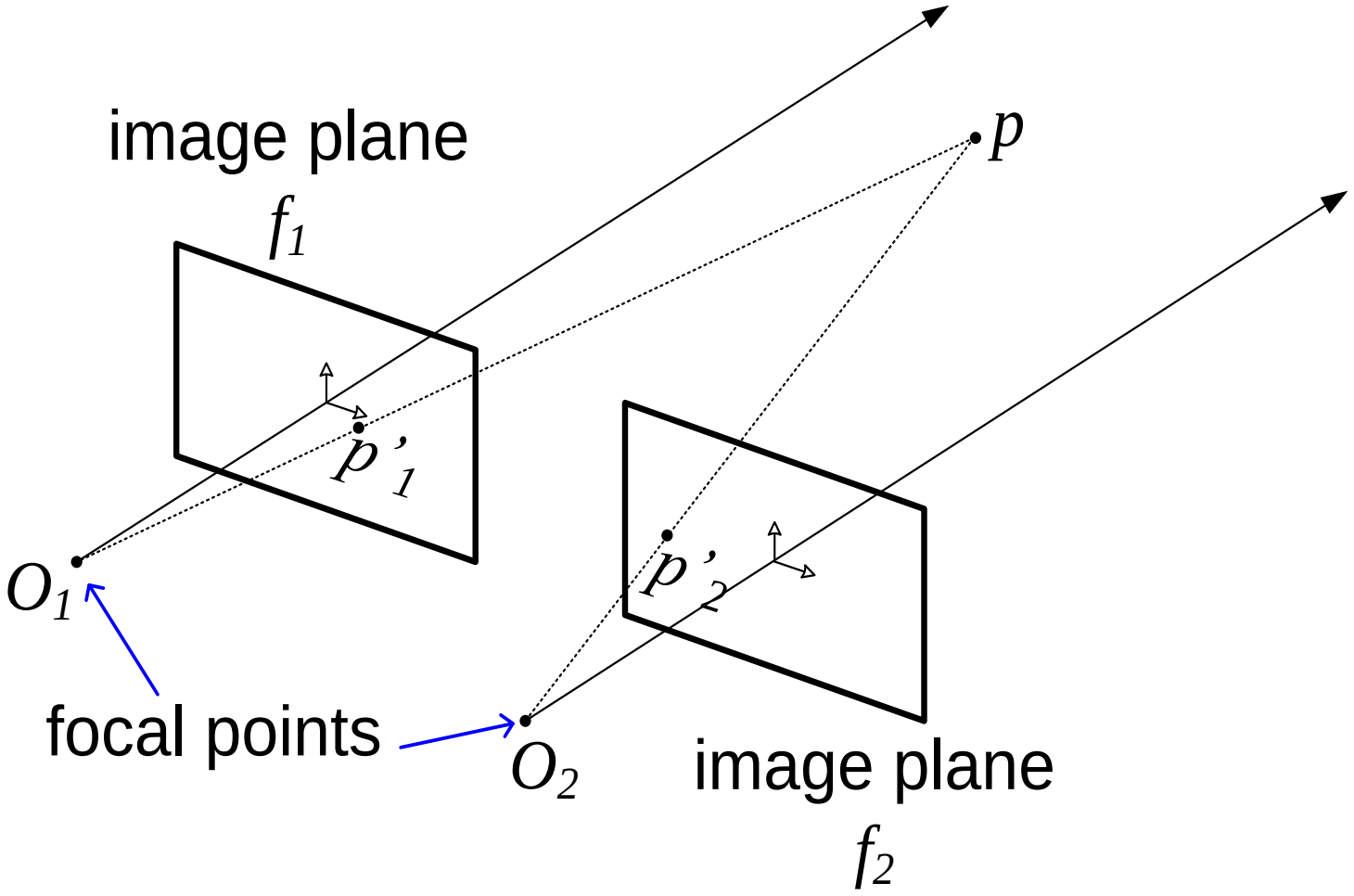
(d) ARTag

Fourier Tag

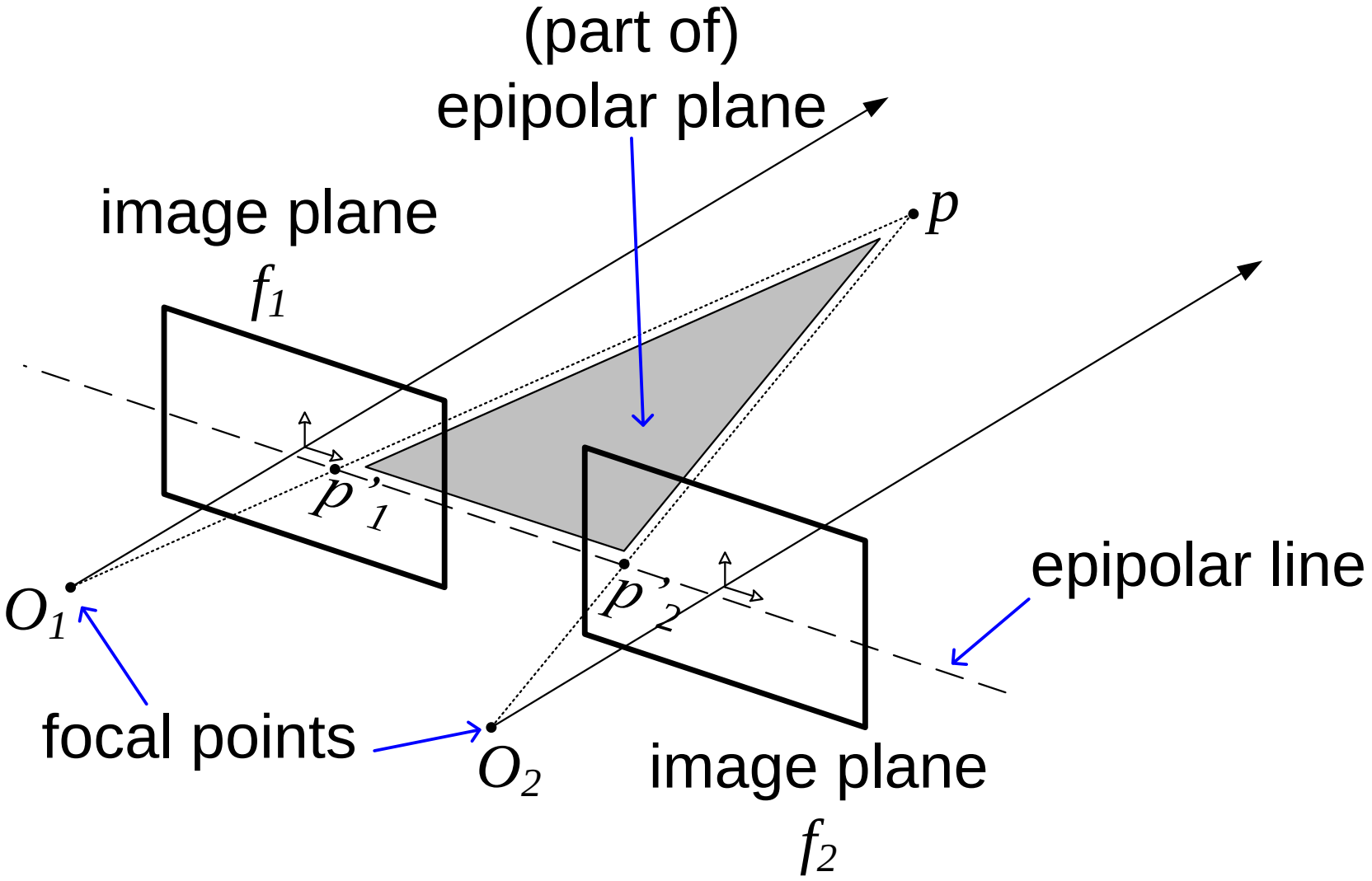
Stereo Vision: Pinhole Camera



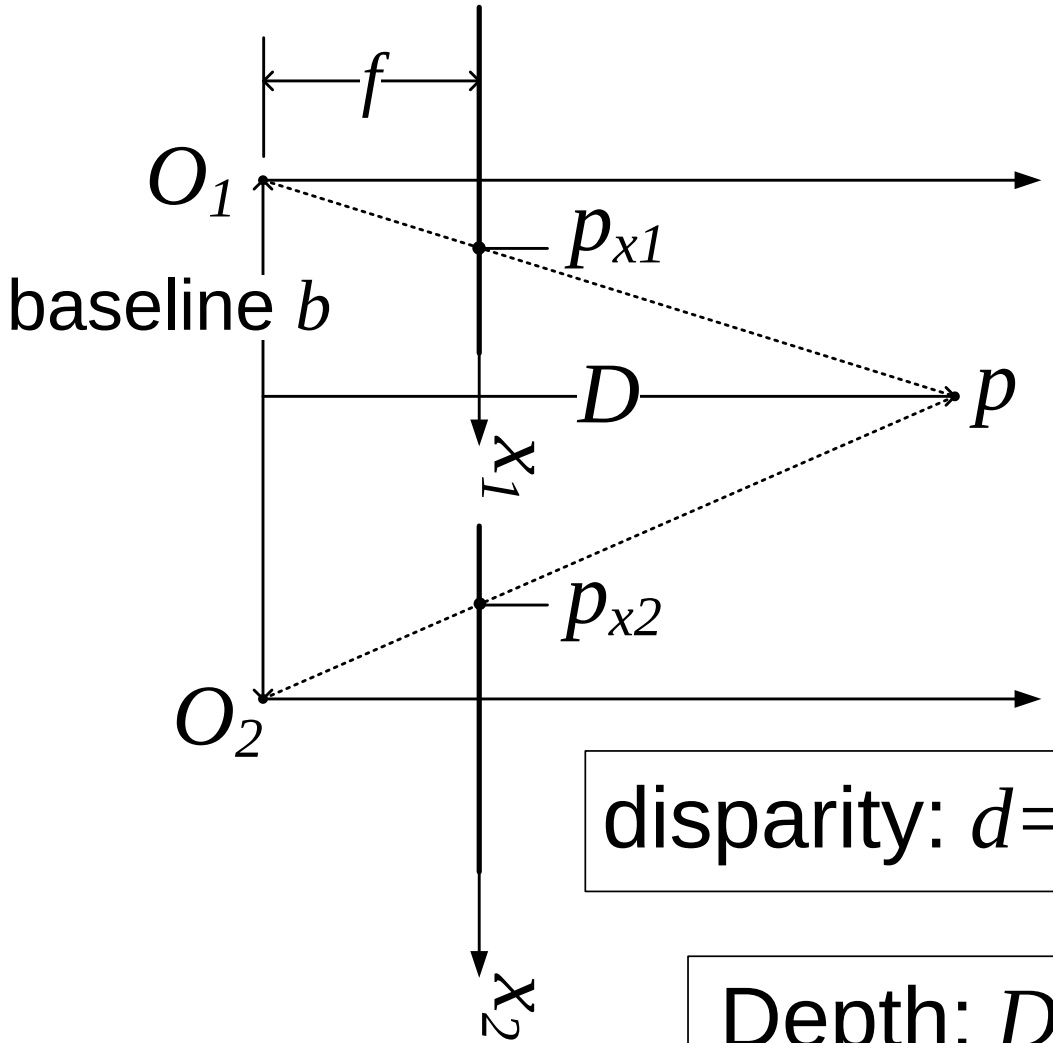
Stereo Vision: Pinhole Camera



Stereo Vision: Pinhole Camera



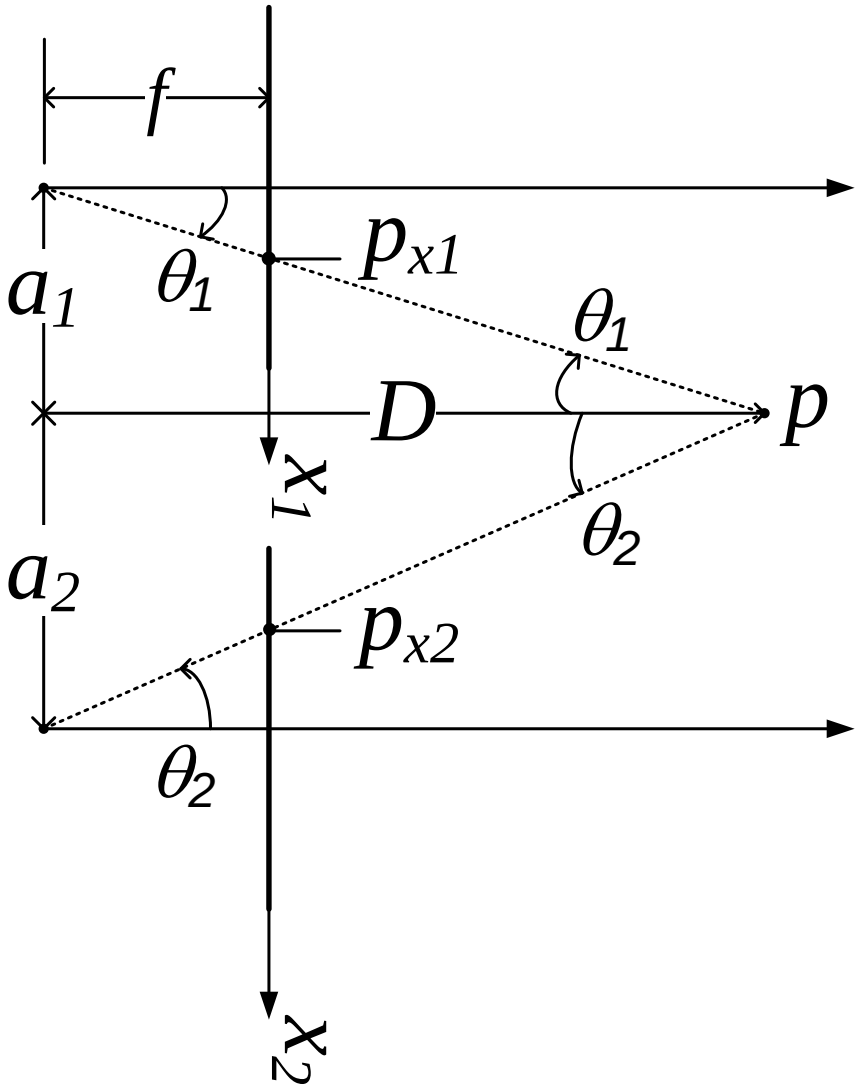
Stereo Vision: Pinhole



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

Depth: $D = fb/d$

Stereo Vision: Pinhole



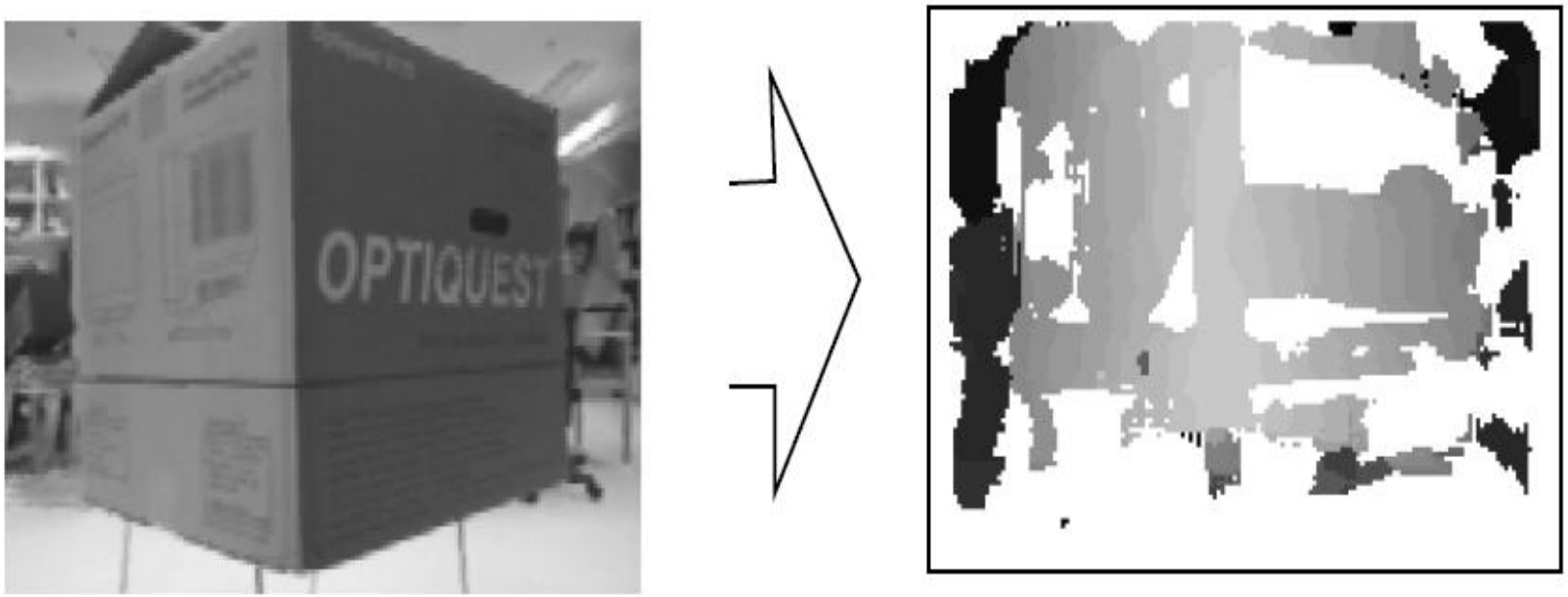
$$\frac{p_{x1}}{f} = \frac{a_1}{D}$$

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

$$a_1 + a_2 = b$$

Large Baseline

Stereo: Disparity Map

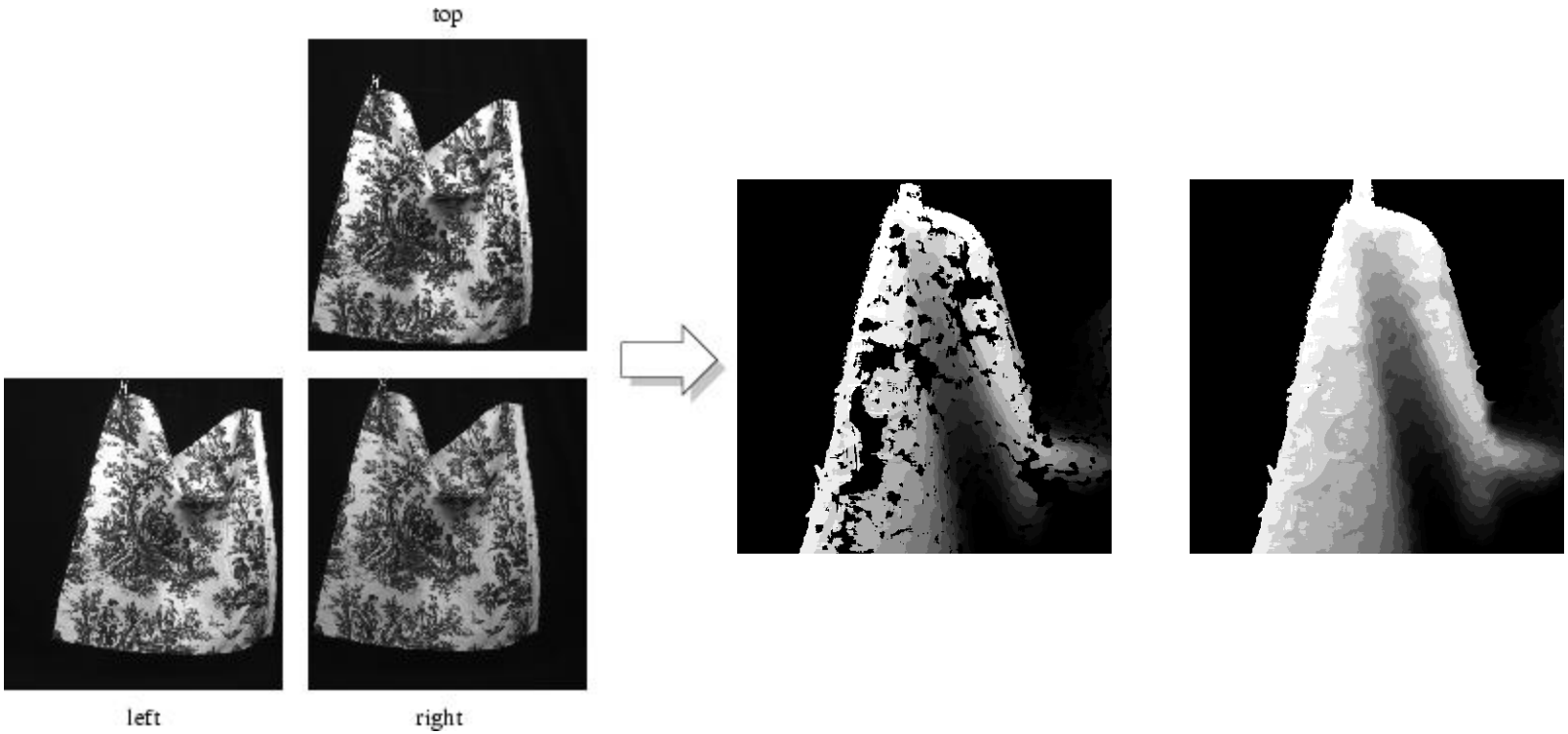


Using real-time stereo vision for mobile robot navigation

Don Murray Jim Little

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

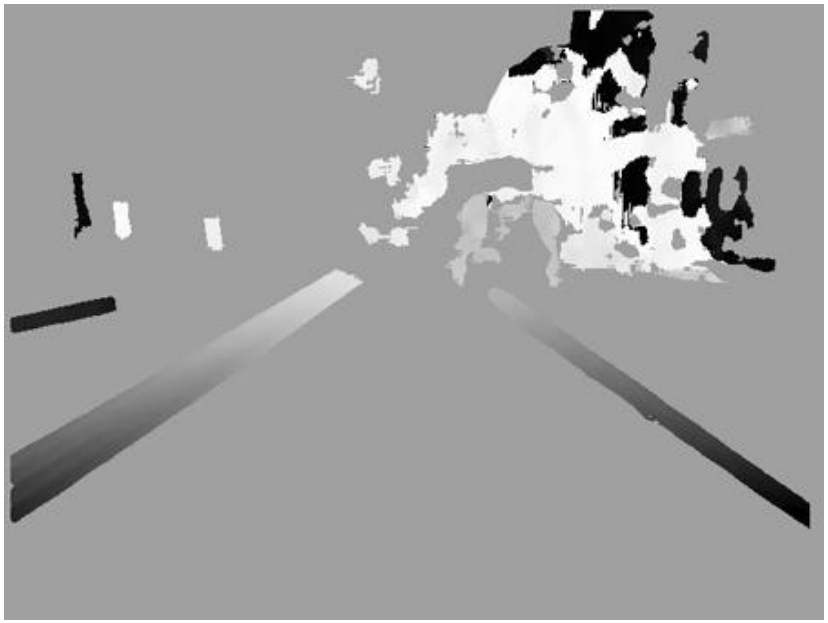
Another Example (Hole Filling)



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:

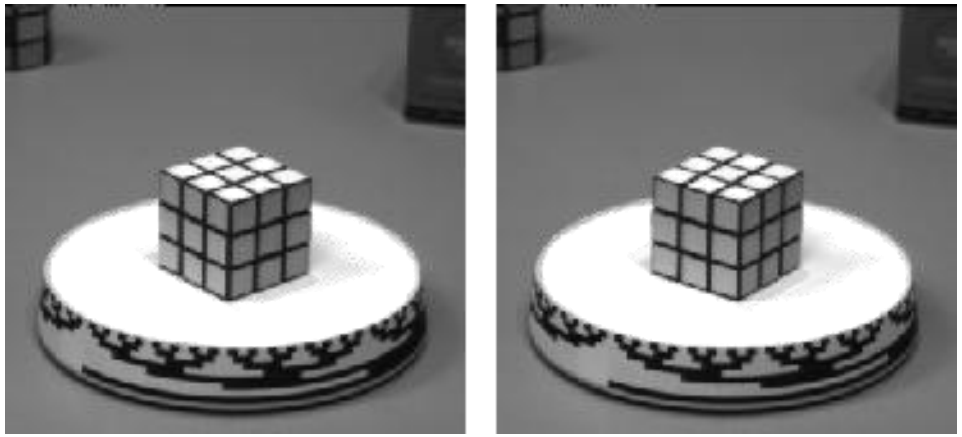
  http://vision.middlebury.edu/stereo/

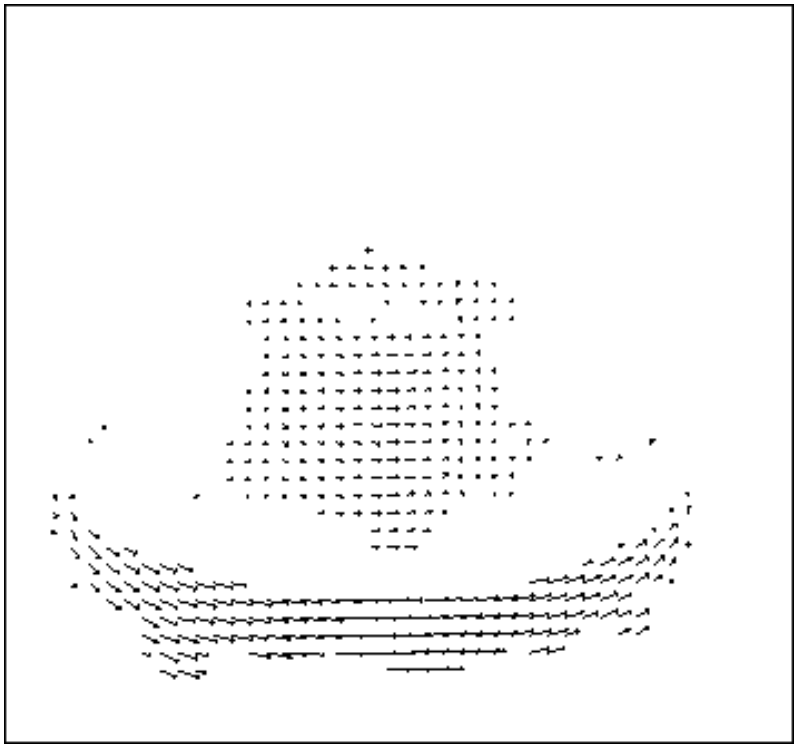
  rank 43 different algorithms.

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

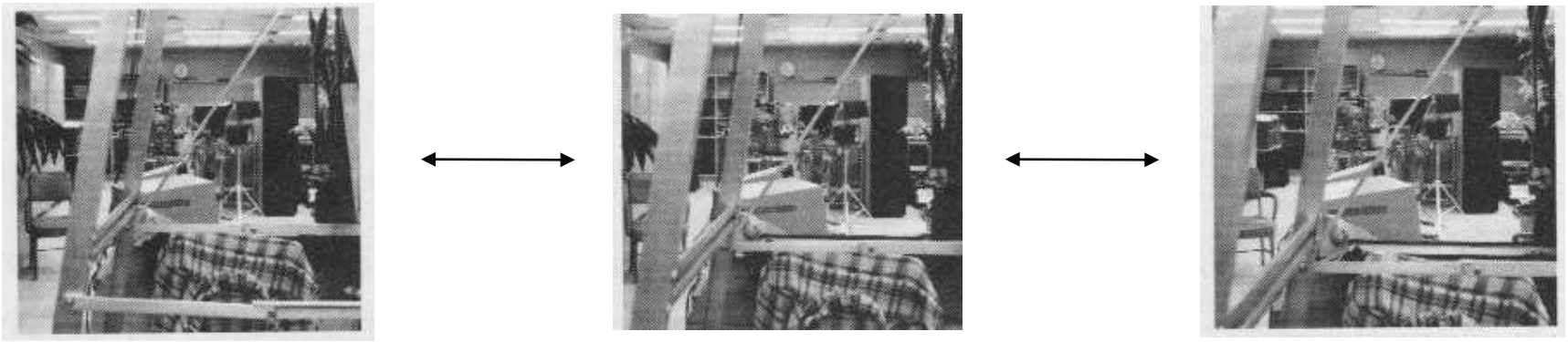




Optical flow

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

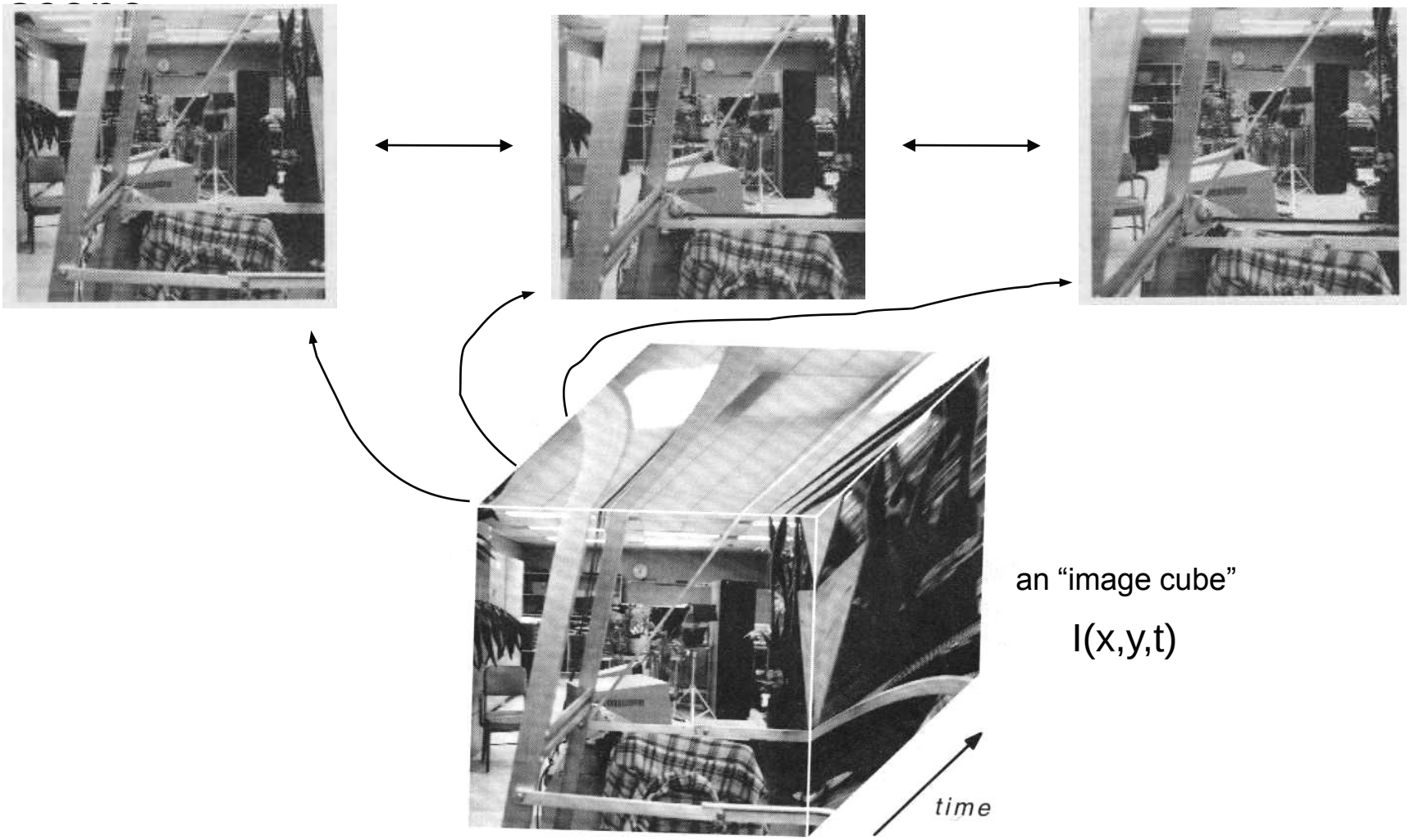
This next step might be to use the image motion to infer scene motion, robot motion or 3D layout.



time sequence of images

Optical flow

Information about *scene motion* rather than the

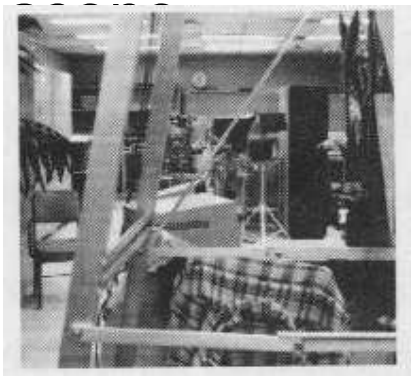


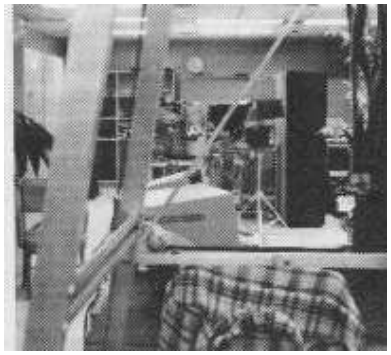
an “image cube”

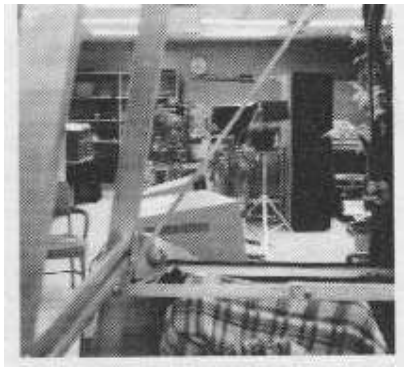
I(x,y,t)

Optical flow

Information about *scene motion* rather than the





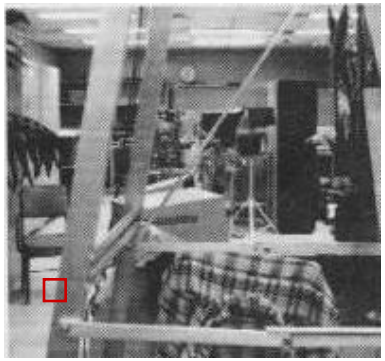


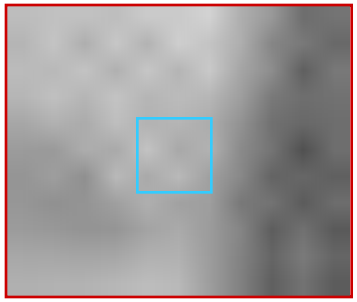
optical flow

How ?

Optical Flow

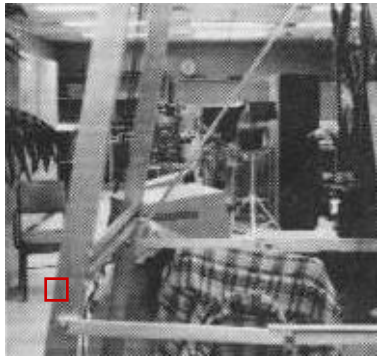
By measuring the direction that intensities are moving...

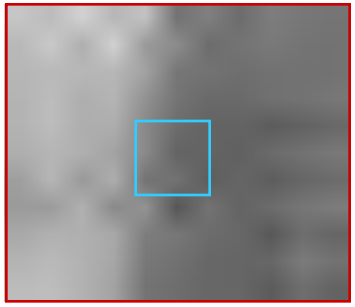




I(x,y,t)

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

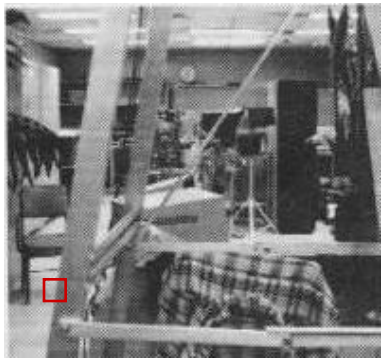
- How can we do this?
- Assume the scene itself is static.
- Find matching chunks in the images.
- An instance of *correspondence*.

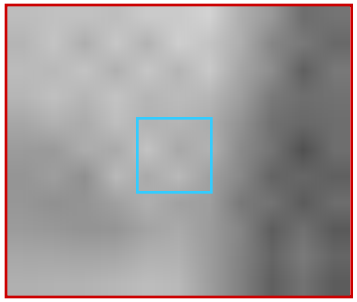
BUT

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

Optical Flow

By measuring the direction that intensities are moving...





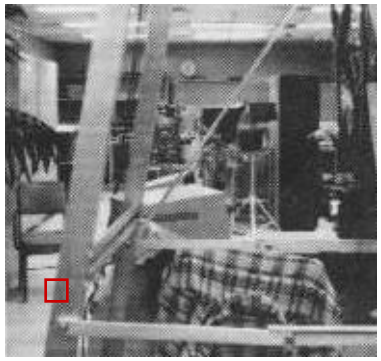
I(x,y,t)

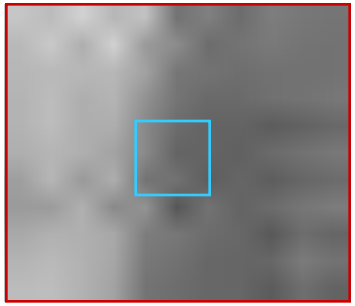
I(x,y,0)

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

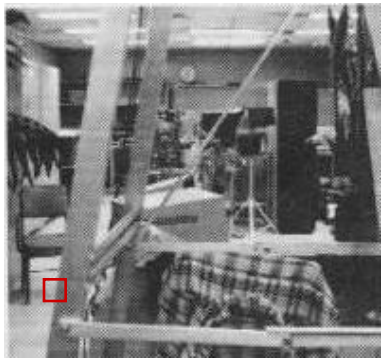
I(0,0,1)

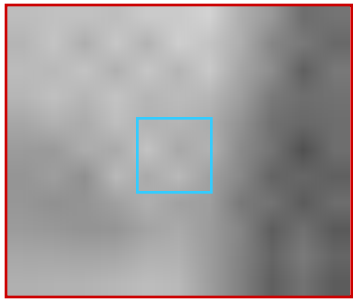
We can estimate things ...

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

Optical Flow

By measuring the direction that intensities are moving...





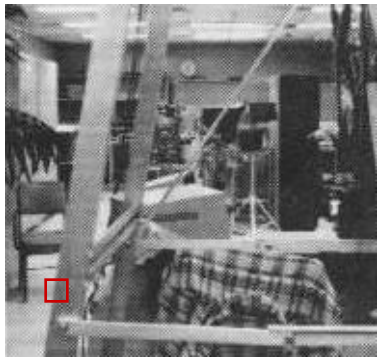
I(x,y,t)

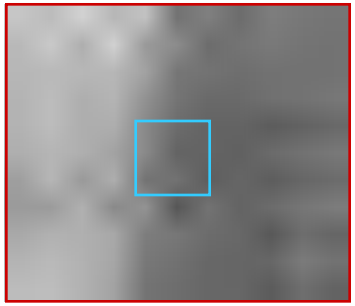
I(x,y,0)

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)

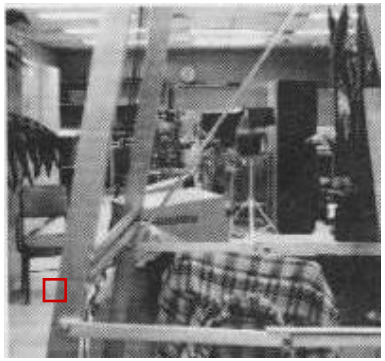
90	90	70	40	25
90	70	40	40	25
90	70	**40**	40	25
90	70	40	40	20
70	50	40	30	15

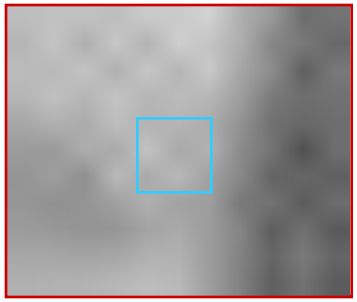
I(0,0,1)

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...

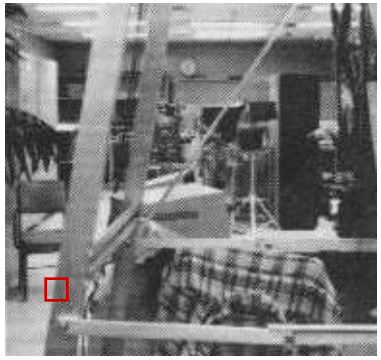


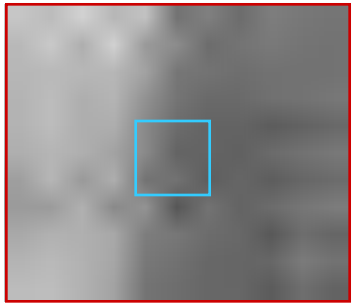


I(x,y,t)

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

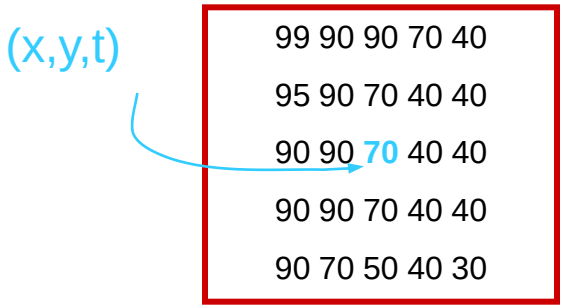
so...

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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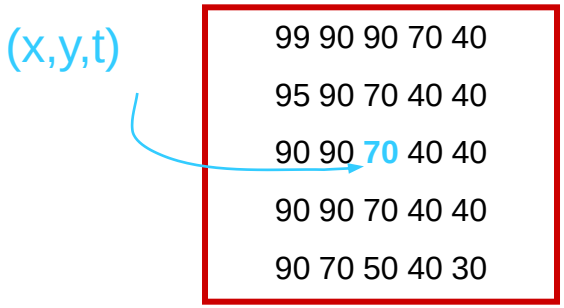
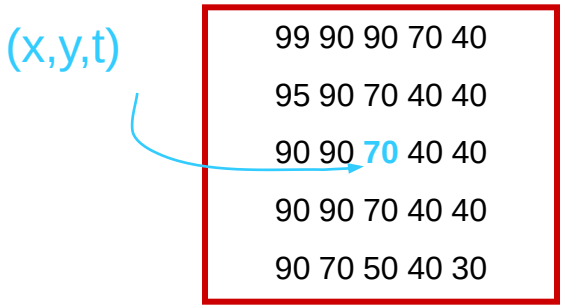


Reminder: $f(x + dx) = f(x) + f'(x)\,dx + f''(x)\,dx^2/2 + \ldots$

Measuring Optical Flow

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



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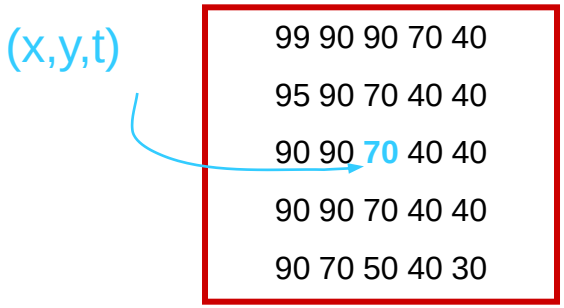
Reminder: $f(x + dx) = f(x) + f'(x)\,dx + f''(x)\,dx^2/2 + \ldots$

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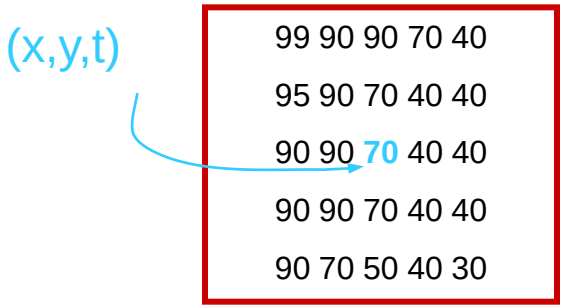
$$I(x,y,t) = I(x,y,t) + I_x\,dx + I_y\,dy + I_t\,dt + \text{2nd deriv. + higher}$$

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

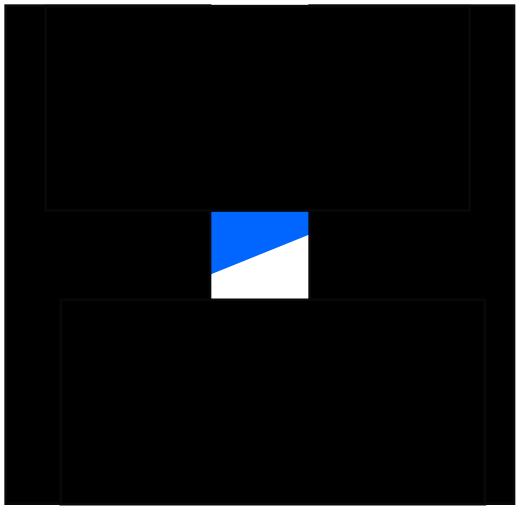
good and bad...

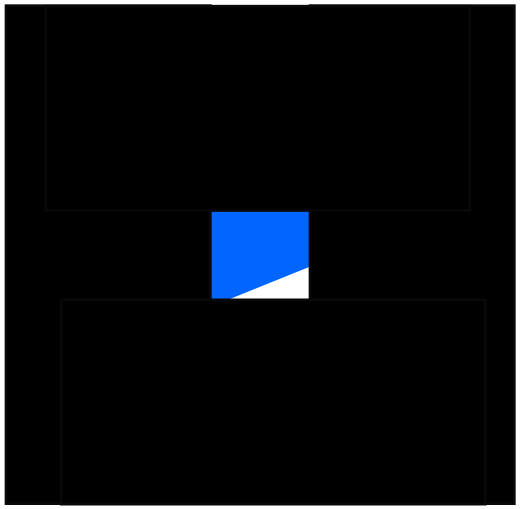
The “aperture” problem

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

- 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...





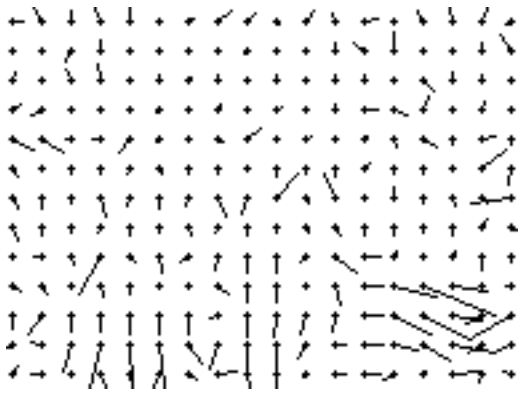
The aperture problem

⟶ 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