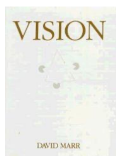
Binocular Stereo Vision

Marr-Poggio-Grimson (MPG)
multi-resolution stereo algorithm



CS332 Visual Processing
Department of Computer Science
Wellesley College

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Key points about human stereo vision

- Image features used for matching:
  ~simple, precise locations, similar between left/right images
- At a single fixation, match features over a limited range of horizontal & vertical disparity
- Eye movements used to match features over larger range of horizontal & vertical disparity
- *Stereo matching is performed at multiple scales*
  - stereo information at different scales is processed ~independently
  - information at coarser scales can be "fused" over a larger range of stereo disparity
  - information at coarser scales can trigger vergence eye movements that narrow the range of stereo disparity in the region of view

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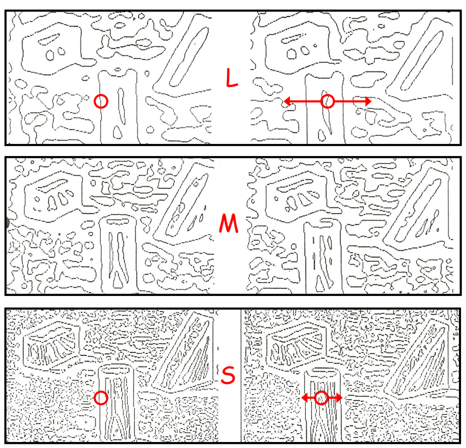
Matching features for the MPG stereo algorithm



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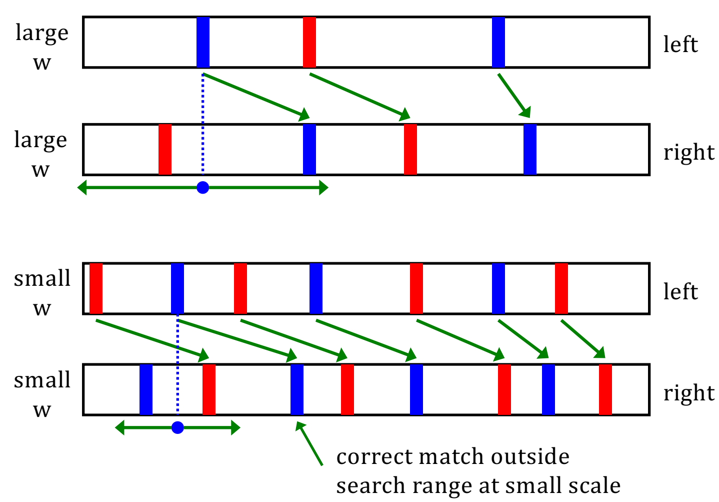

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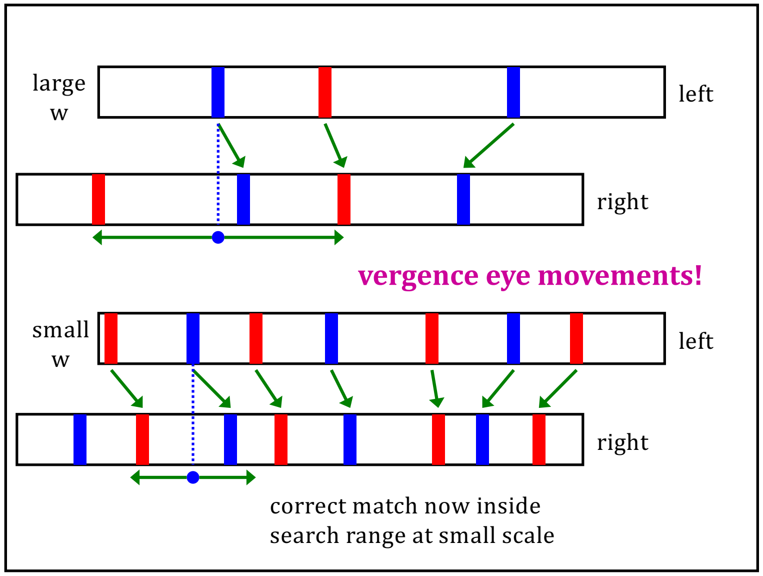
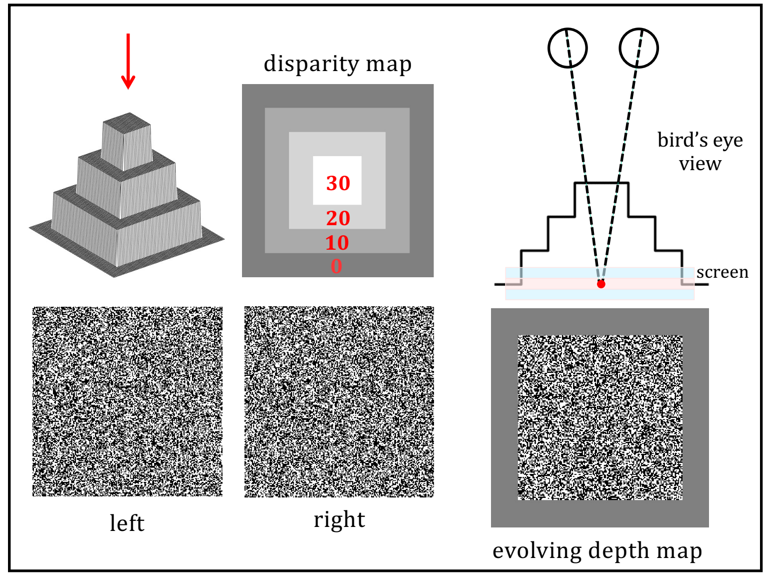
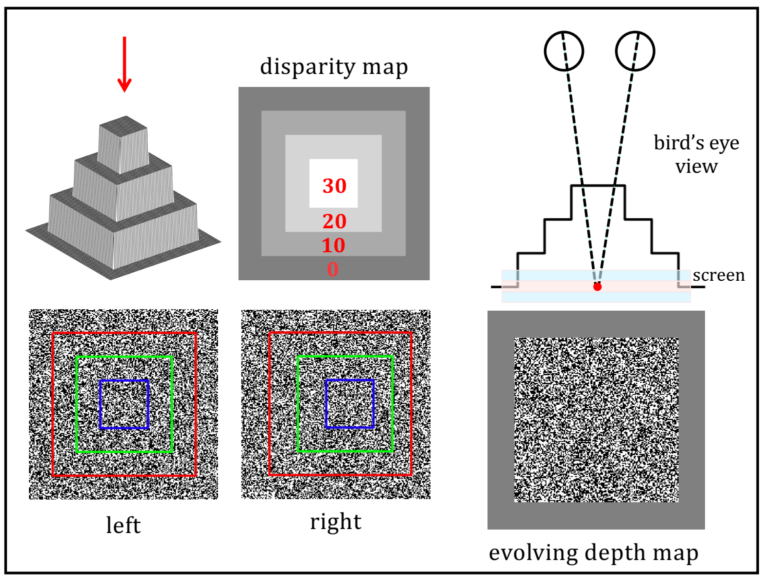

large
w
left
right
vergence eye movements!
small
w
left
right
correct match now inside
search range at small scale

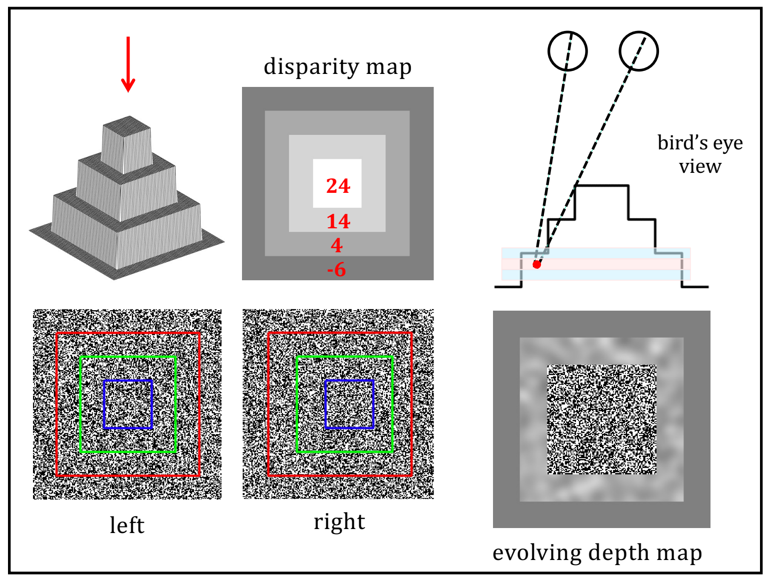
5


disparity map
30
20
10
0
bird's eye
view
screen
left
right
evolving depth map

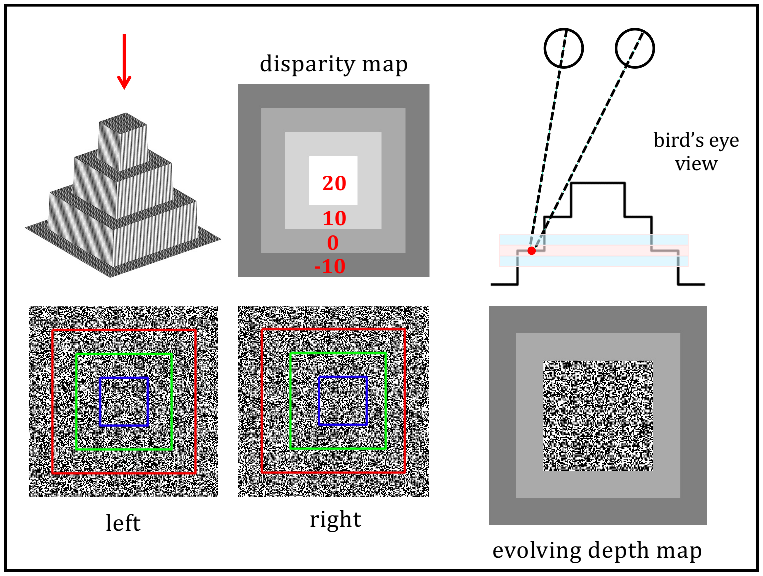
6


disparity map
30
20
10
0
bird's eye
view
screen
left
right
evolving depth map

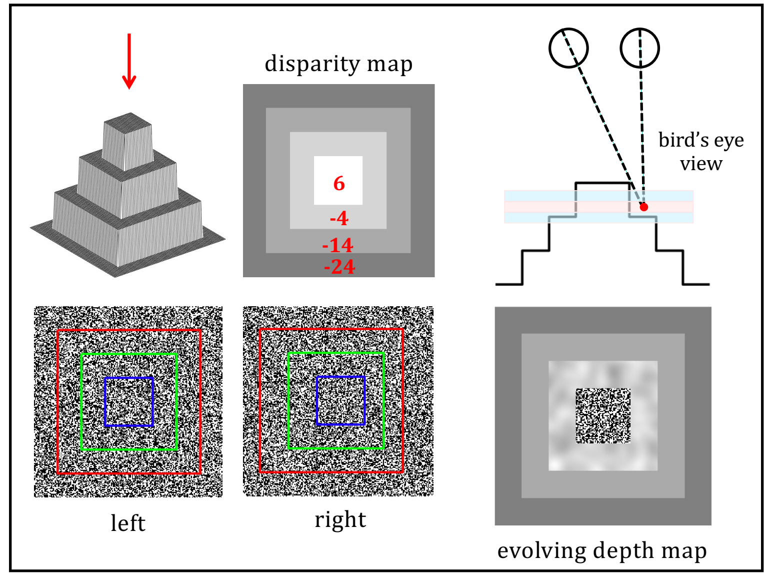
7


disparity map
24
14
4
-6
bird's eye
view
left
right
evolving depth map

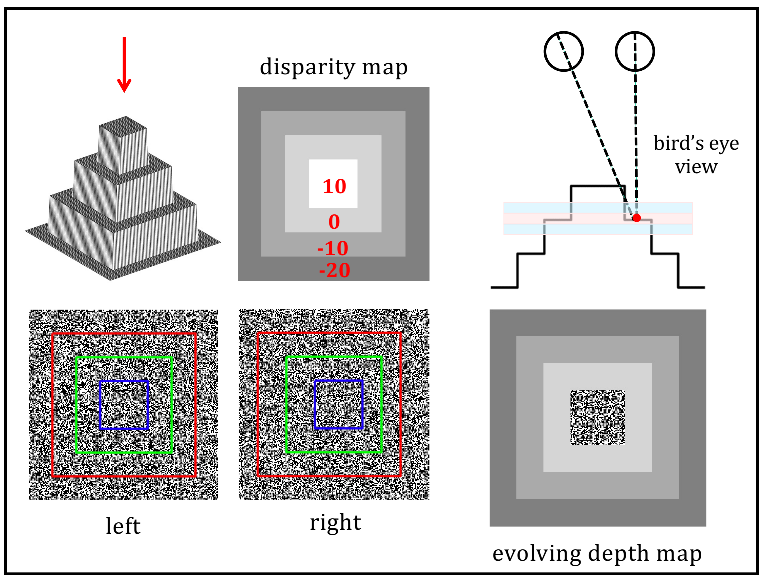
8


disparity map
20
10
0
-10
bird's eye view
left
right
evolving depth map

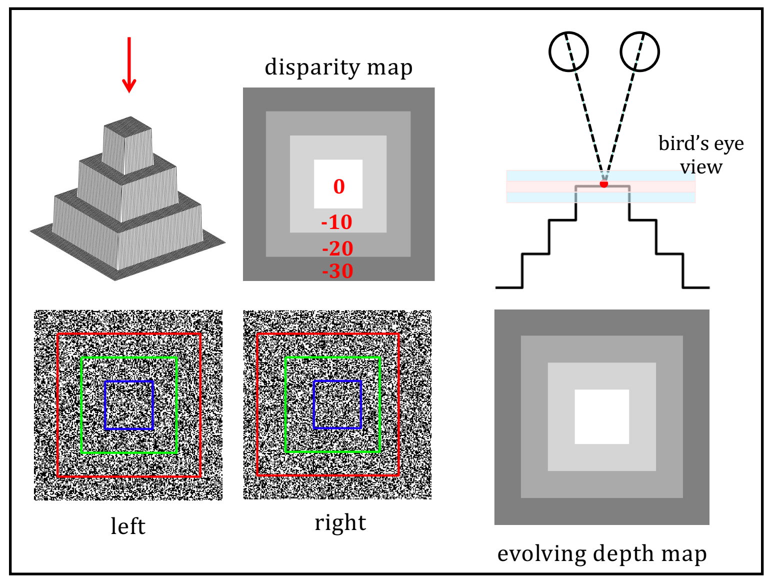
9


disparity map
6
-4
-14
-24
bird's eye view
left
right
evolving depth map

10


disparity map
10
0
-10
-20
bird's eye view
left
right
evolving depth map

11


disparity map
0
-10
-20
-30
bird's eye view
left
right
evolving depth map

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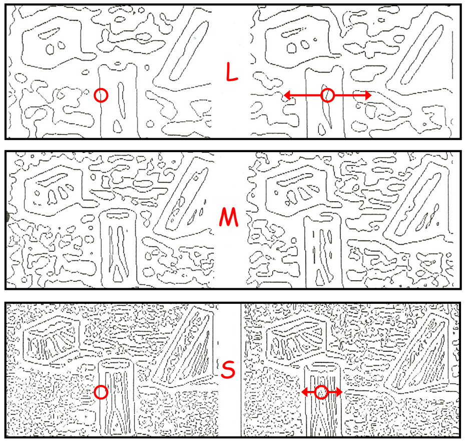
Matching features for the MPG stereo algorithm



zero-crossings of image convolutions with $\nabla^2 G$ operators of different size

rough disparities over large range

communicate

accurate disparities over small range

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Stereo images (Tsukuba, CMU)

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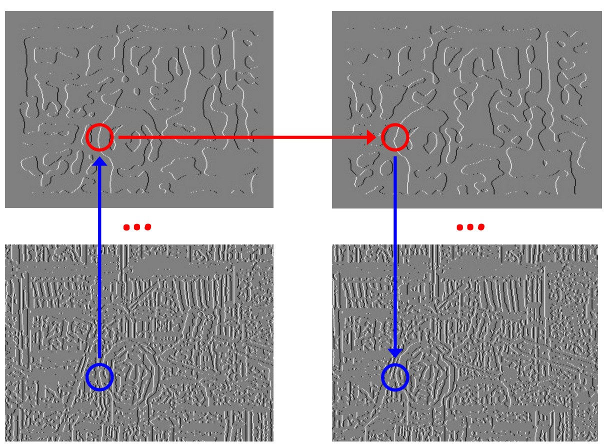
Zero-crossings for stereo matching



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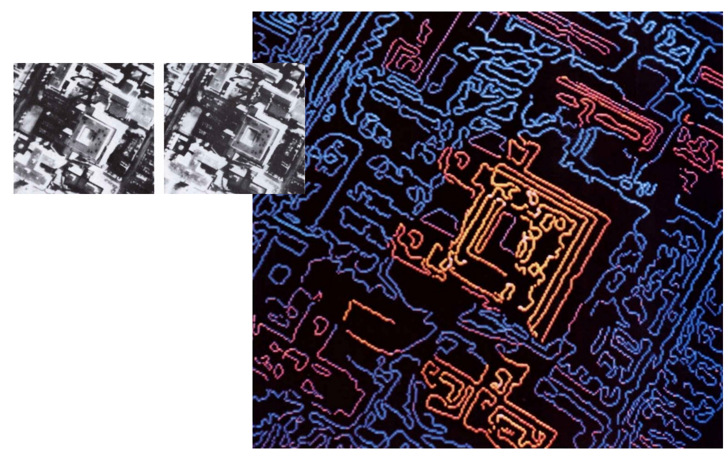
MPG stereo algorithm results



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Simplified MPG algorithm, Part 1

To determine initial correspondence:

(1) Find zero-crossings using a $\nabla^2 G$ operator with central positive width w

(2) For each horizontal slice:

(2.1) Find the nearest neighbors in the right image for each zero-crossing fragment in the left image

(2.2) Find the nearest neighbors in the left image for each zero-crossing fragment in the right image

(2.3) For each pair of zero-crossing fragments that are closest neighbors of one another, let the right fragment be separated by $\delta_{initial}$ from the left. Determine whether $\delta_{initial}$ is within the matching tolerance, m. If so, consider the zero-crossing fragments matched with disparity $\delta_{initial}$

$m = w/2$

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Simplified MPG algorithm, Part 2

To determine final correspondence:

(1) Find zero-crossings using a $\nabla^2 G$ operator with reduced width w/2

(2) For each horizontal slice:

(2.1) For each zero-crossing in the left image:

(2.1.1) Determine the nearest zero-crossing fragment in the left image that matched when the $\nabla^2 G$ operator width was w

(2.1.2) Offset the zero-crossing fragment by a distance $\delta_{initial}$, the disparity of the nearest matching zero-crossing fragment found at the lower resolution with operator width w

(2.2) Find the nearest neighbors in the right image for each zero-crossing fragment in the left image

(2.3) Find the nearest neighbors in the left image for each zero-crossing fragment in the right image

(2.4) For each pair of zero-crossing fragments that are closest neighbors of one another, let the right fragment be separated by δ_{new} from the left. Determine whether δ_{new} is within the reduced matching tolerance, m/2. If so, consider the zero-crossing fragments matched with disparity $\delta_{final} = \delta_{new} + \delta_{initial}$

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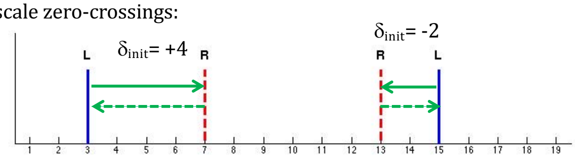
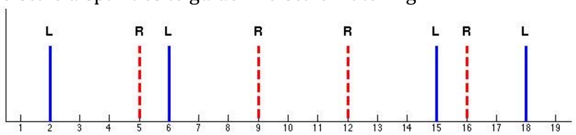
Coarse-scale zero-crossings:

w = 8
m = 4



Use coarse-scale disparities to guide fine-scale matching:

w = 4
m = 2



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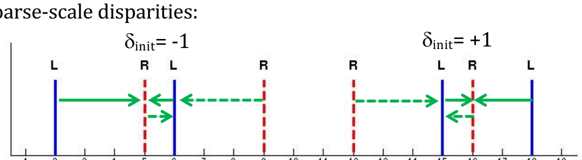
m = 2



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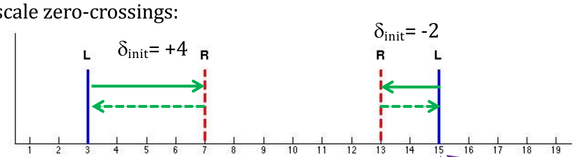

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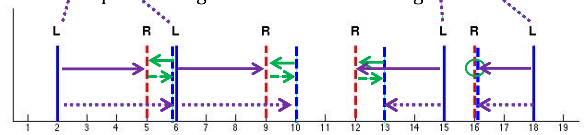
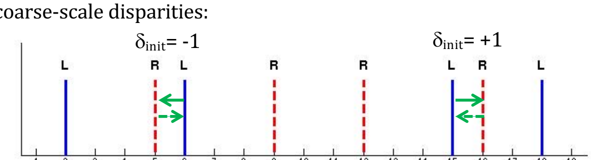


Ignore coarse-scale disparities:

w = 4
m = 2



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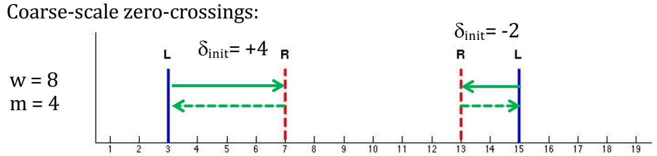
Coarse-scale zero-crossings:



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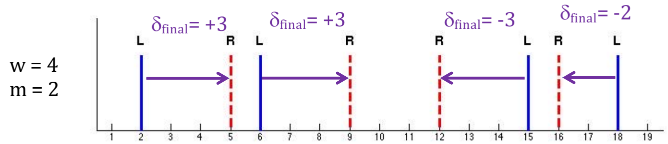
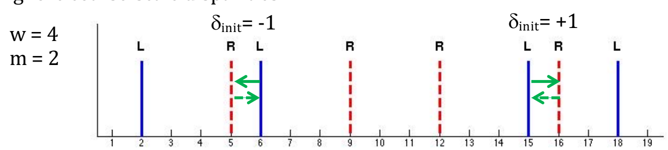


Ignore coarse-scale disparities:



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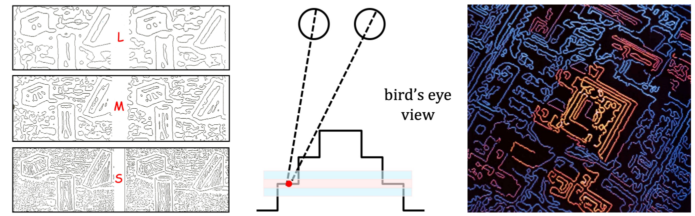
MPG stereo correspondence algorithm

- multi-resolution, feature-based stereo matching algorithm



- incorporates role of vergence eye movements and multi-scale processing observed in human stereo vision
- implemented in a computer vision system
- simplified version can be hand simulated to better understand interactions across scales

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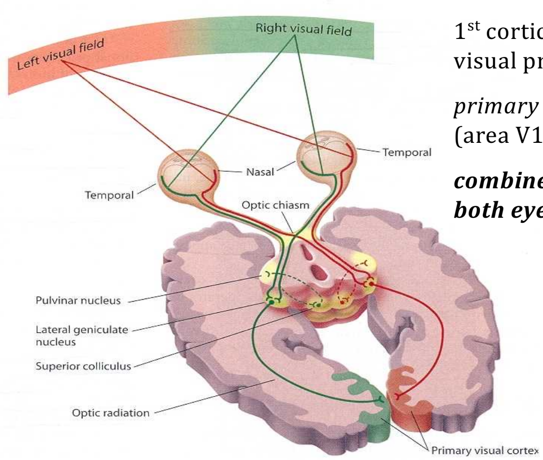
Projection from the retina



1st cortical stage of visual processing:

primary visual cortex (area V1)

combines input from both eyes

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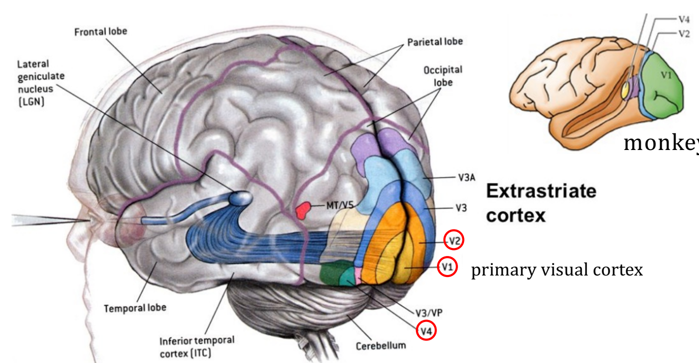
Neural processing of stereo disparity



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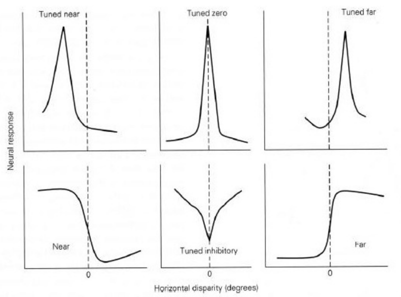
Neural mechanisms for stereo processing



From G. Poggio & others:
- neural recordings from monkey (area V1)
- viewing random-dot stereograms

zero disparity: at fixation distance

near: in front of fixation distance

far: behind fixation distance

- (some) simple & complex cells in **area V1** are *selective for stereo disparity*
- neurons with large receptive fields are selective for a larger range of disparity

... but the stereo correspondence problem is ***not solved*** in V1!!

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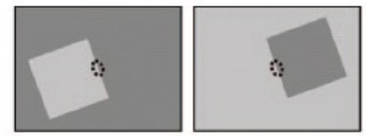
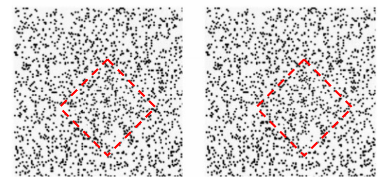
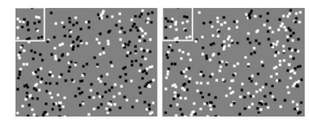
Selectivity for *stereo boundaries* in V2





Von der Heydt & colleagues:

Some V2 cells are selective for the orientation, contrast, and *side of border ownership* of an edge ... for edges defined by luminance *or stereo disparity*



"anti-correlated" stereogram

Later, in area V4, neural responses to stereo disparity appear to correspond more closely to perceived depth

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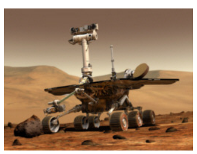
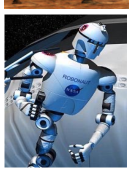
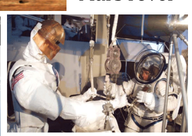
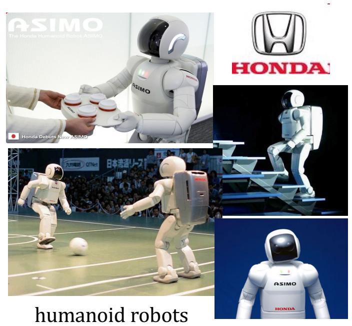


Spirit
Mars rover



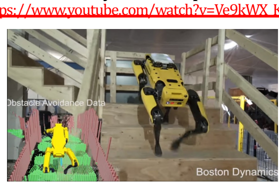


Robonaut to the rescue!



humanoid robots

Boston Dynamics SpotMini
https://www.youtube.com/watch?v=Ve9kWX_KXus



Boston Dynamics Atlas Robot
https://www.youtube.com/watch?v=O0ni8Uz3O0I

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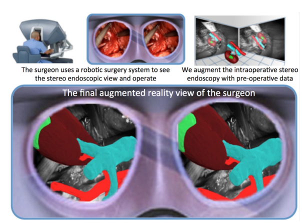
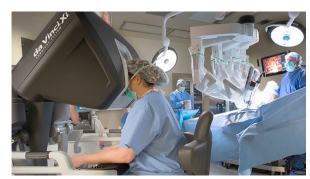
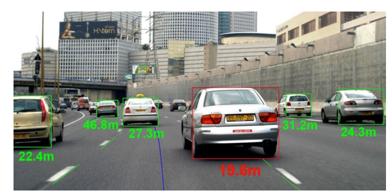
Stereo visualization for image guided surgery





Da Vinci surgical robot

MobileEye



Stereo vision for automated vehicles

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