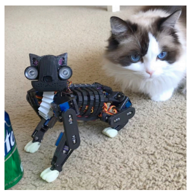
Binocular Stereo Vision

Neural processing of stereo disparity

Marr-Poggio-Grimson
multi-resolution stereo algorithm

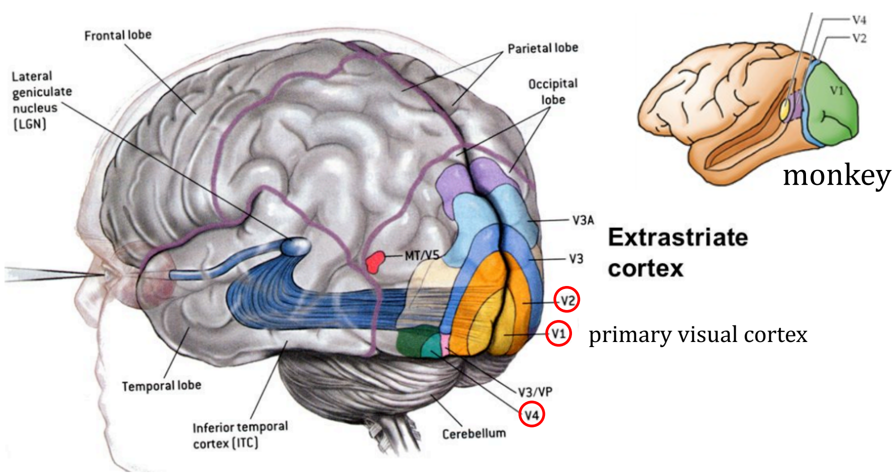
Stereo vision applications



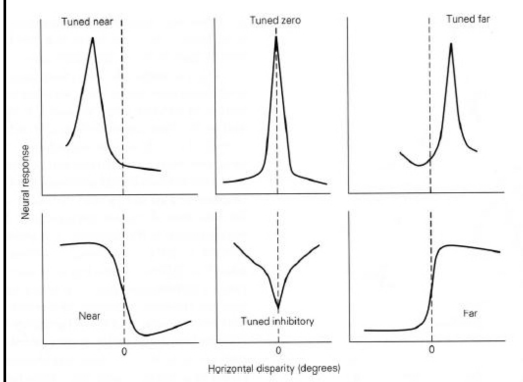
CS332 Visual Processing

Department of Computer Science
Wellesley College

Neural processing of stereo disparity



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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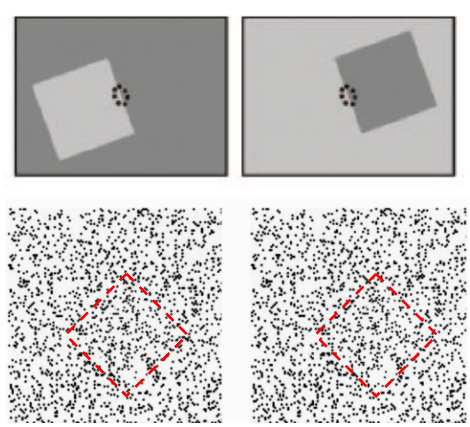
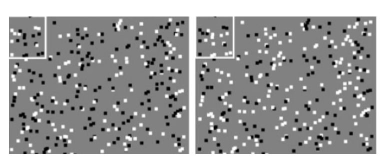
Selectivity for *stereo boundaries* in V2



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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In summary, some key points…

- Image features used for matching:
  ~simple, precise locations, similar between left/right images
- At single fixation, match features over a limited range of horizontal & vertical disparity
- Eye movements used to match features over larger range of disparity
- Stereo matching performed at multiple scales
  ~independently, disparity range depends on scale
- Neurons selective for different ranges of stereo disparity, multiple processing stages V1 → V2 → V4

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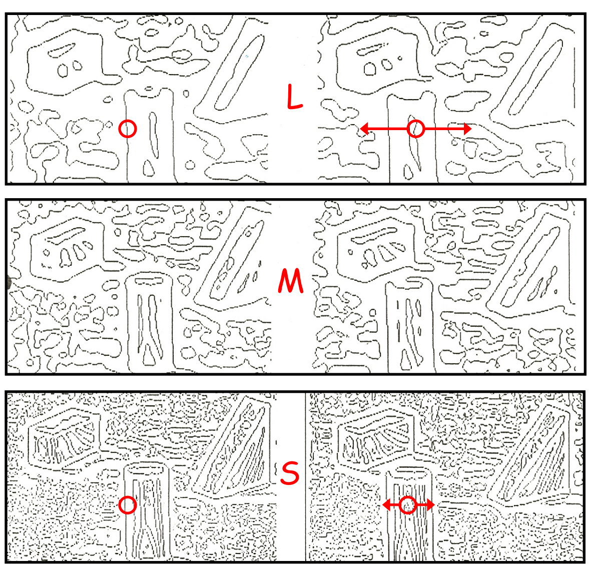
Matching features for the MPG stereo algorithm



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

rough disparities over large range

accurate disparities over small range

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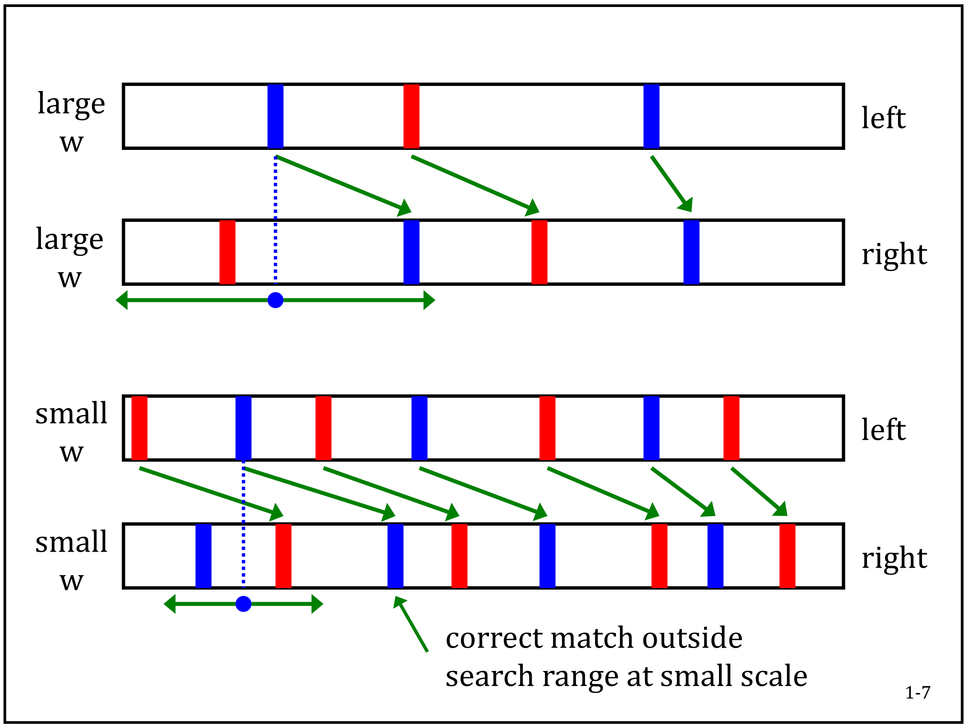
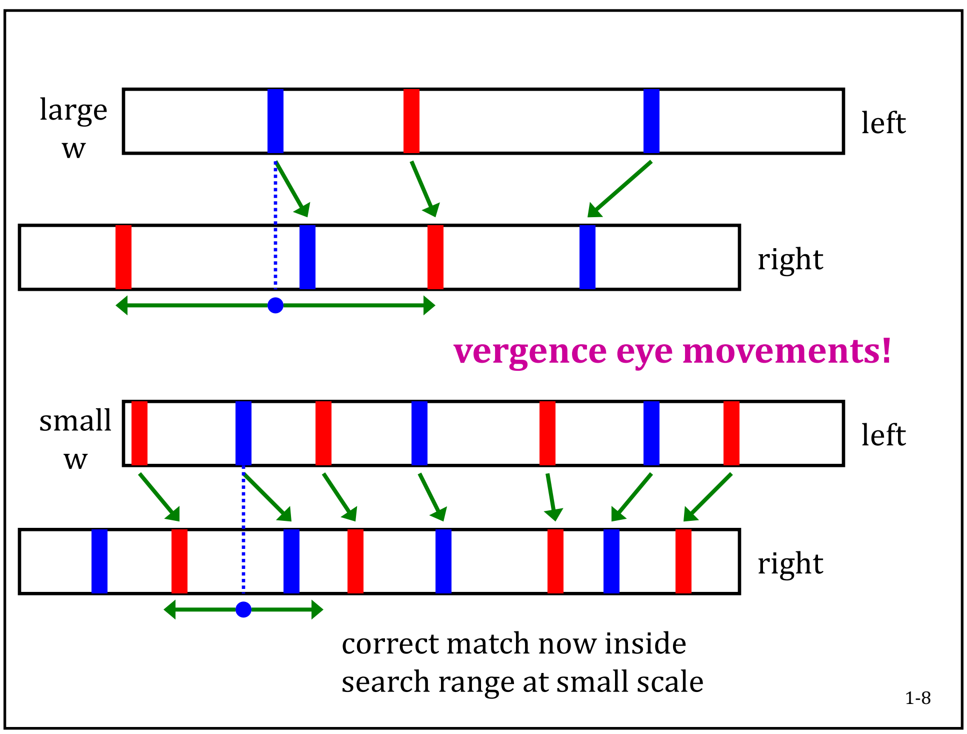
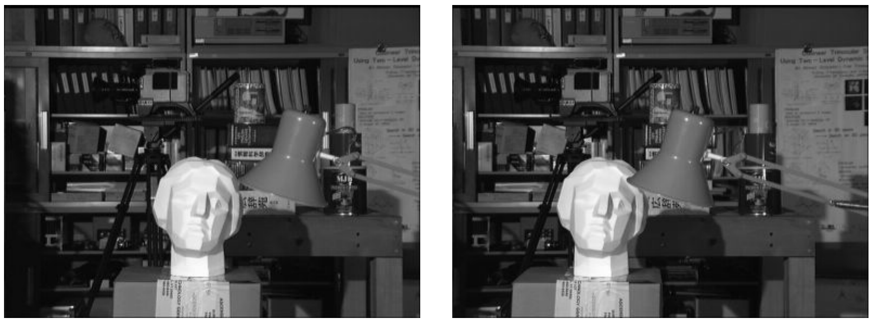

large
w
left
large
w
right
small
w
left
small
w
right
correct match outside
search range at small scale
1-7


large
w
left
right
vergence eye movements!
small
w
left
right
correct match now inside
search range at small scale
1-8

Stereo images (Tsukuba, CMU)



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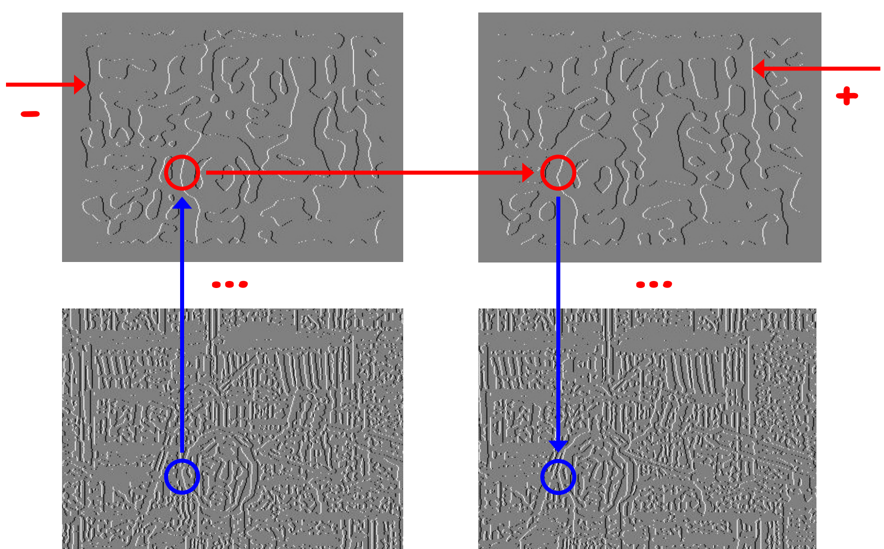
Zero-crossings for stereo matching



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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) Fine 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) Fine 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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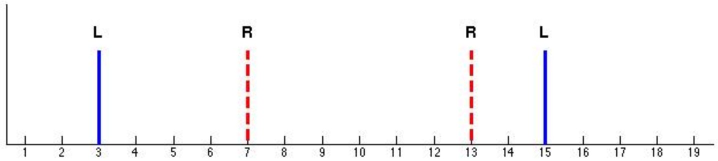
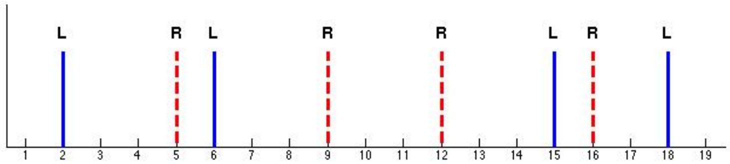
Coarse-scale zero-crossings:

w = 8
m = 4



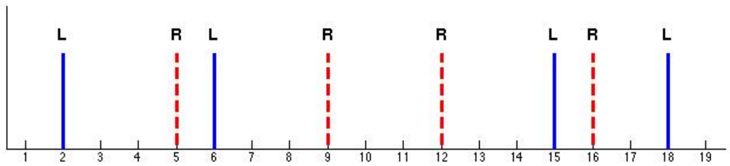
Use coarse-scale disparities to guide fine-scale matching:

w = 4
m = 2



Ignore coarse-scale disparities:

w = 4
m = 2



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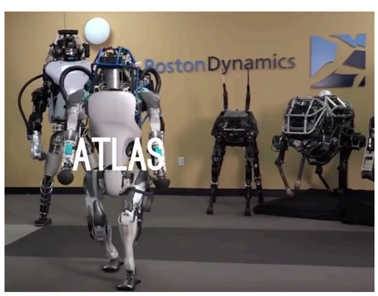
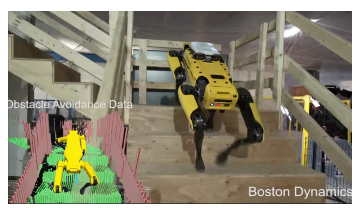
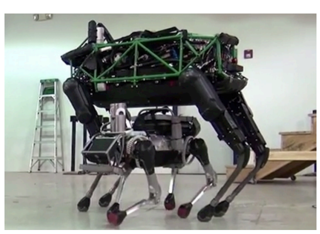
Stereo vision applications - robots



Boston Dynamics Atlas Robot
https://www.youtube.com/watch?v=QQni8Uz3Q0I



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



Carnegie Robotics MultiSense S7
https://carnegierobotics.com/multisense-s7/

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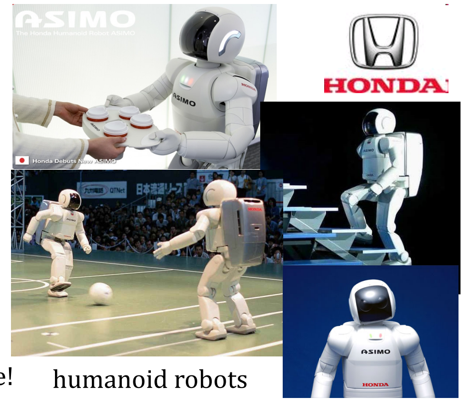
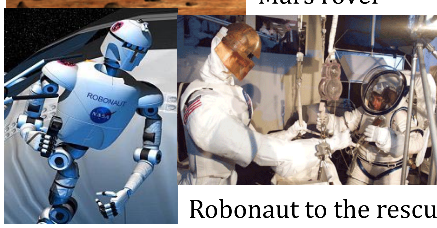
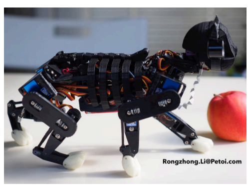
Spirit
Mars rover

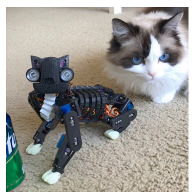




Robonaut to the rescue!

humanoid robots

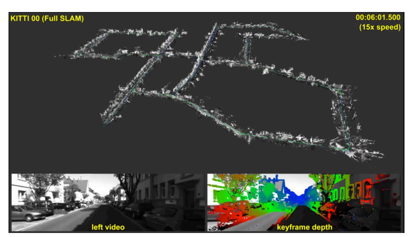




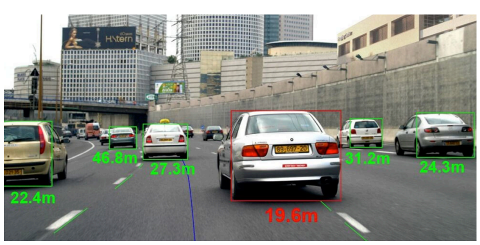
security robots

OpenCat – stay tuned!
https://www.hackster.io/petoi/opencat-845129

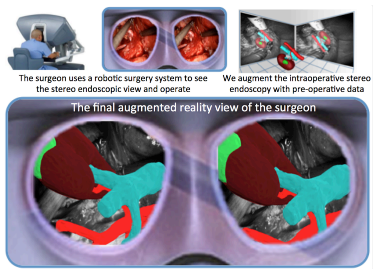
Stereo vision applications - driving

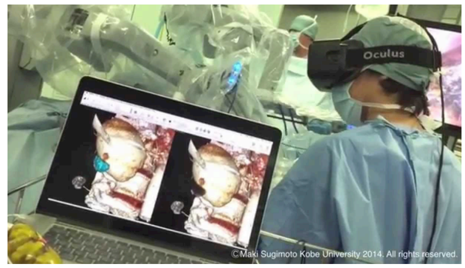


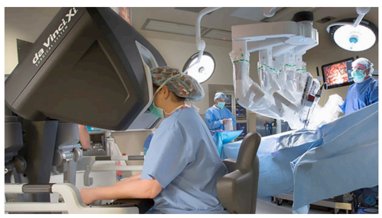
SLAM: Simultaneous Localization and Mapping
https://www.youtube.com/watch?v=oJt3Ln8H03s



Stereo visualization for image guided surgery

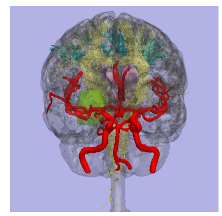






Da Vinci surgical robot

CMU 3D overlay system



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