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Discussion of Models for Angular Velocity Detection in Visual Flight Control of Honeybee

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CONTENT

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- Elementary Motion Detector model
- Angular Velocity Detector Model
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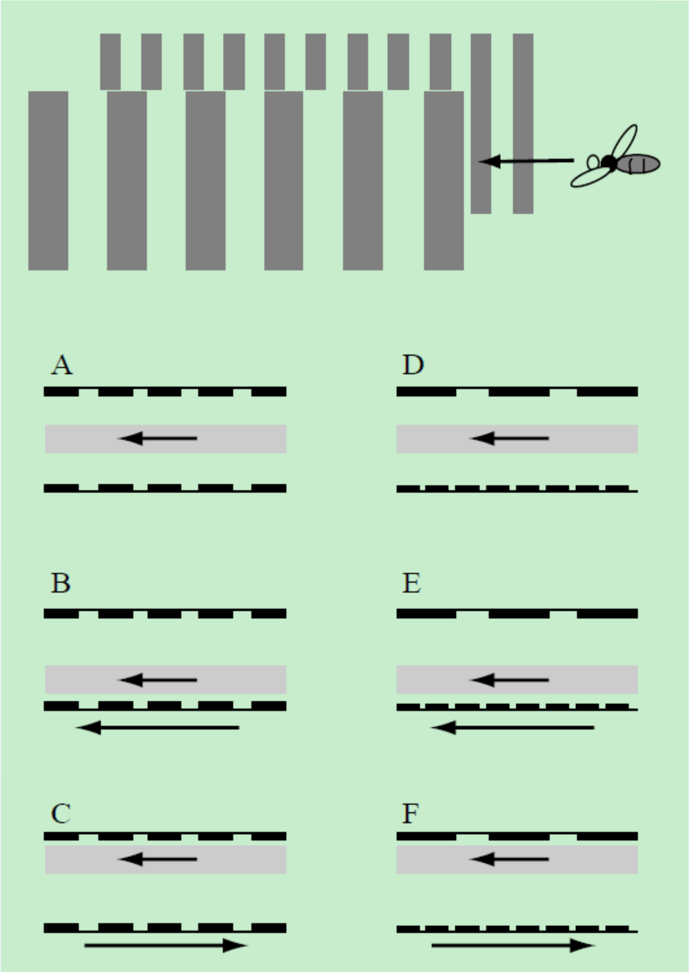
- Corridor Experiments

Bees are capable of navigating complex environment. Experiments(Srinivasan, 1996) show that

- ➢ Honeybees can estimate speed of image moving through their compound eyes
- ➢ The flight control is independent of spatial structure
- ➢ The bees use the angular velocity of moving image in both eyes to keep flying in the "center" of the tunnel. They sense distance to the wall by image velocity.

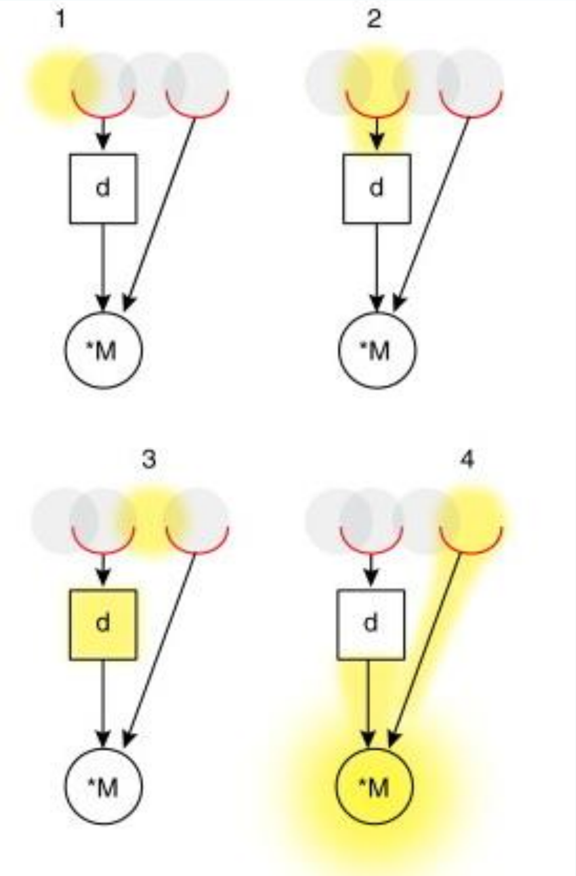


- Srinivasan, M., Zhang, S., Lehrer, M., & Collett, T. (1996). Honeybee navigation en route to the goal: visual flight control and odometry. Journal of Experimental Biology, 199(Pt 1), 237-244.

- EMD model

Elementary motion detector model is first proposed by Reichardt in 1957 to describe motion sensitivity in animal vision. The main idea is that:

- The signal captured from photoreceptor A is delayed
- And then correlated with signal from B without delay
- The model produces a strong output the image move from A to B

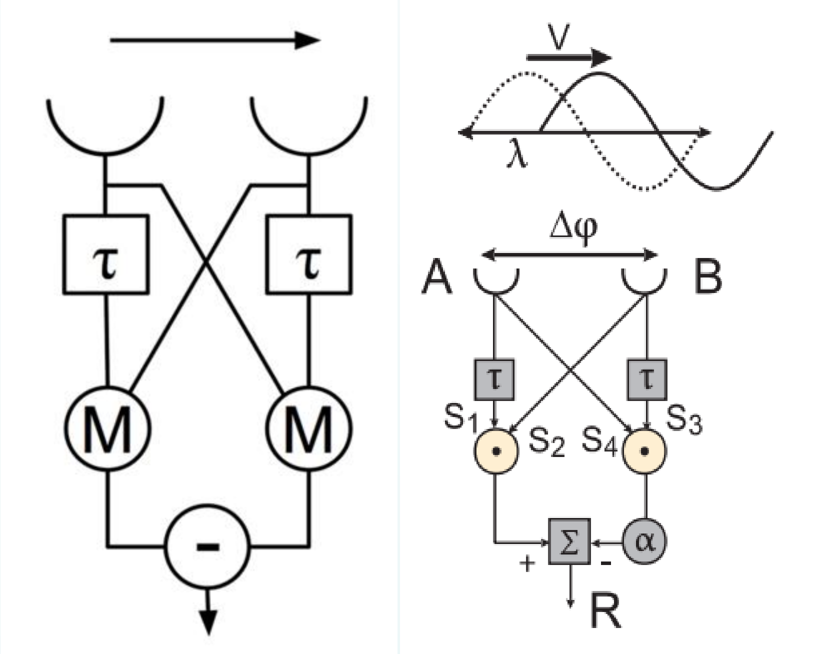


- Eichner, H., Joesch, M., Schnell, B., Reiff, D. F., & Borst, A. (2011). Internal structure of the fly elementary motion detector. Neuron, 70(6), 1155-64.

- EMD model

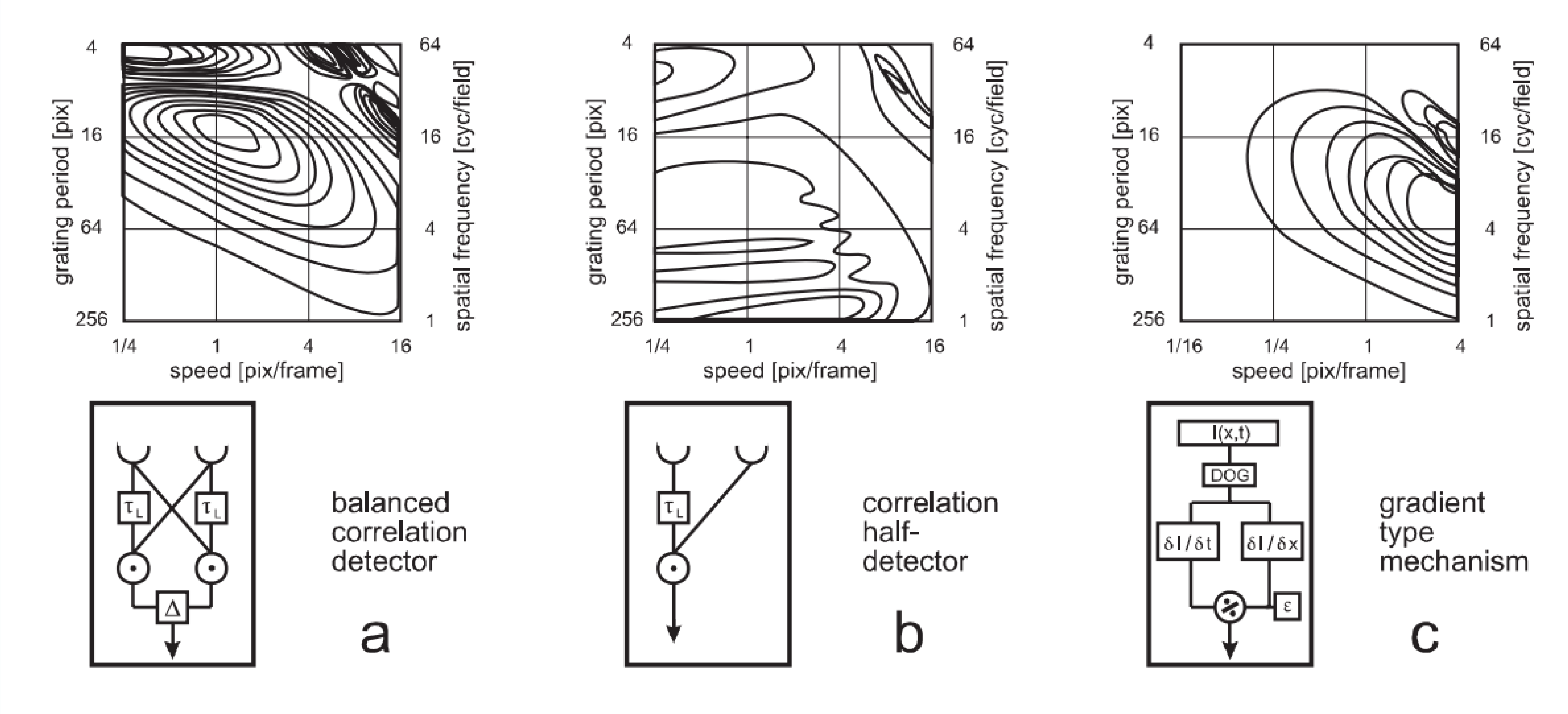
Elementary motion detector then developed a lot.

- ➢ First it was generalized to a antisymmetric model which subtracts right arm response from left to get a directional selective model(positive for progressive and negative for regressive)
- ➢ Then Zanker proposed that multiply a number between 0 and 1 before subtraction can tune the speed response of the model.



- Zanker, J. M., Srinivasan, M. V., & Egelhaaf, M. (1999). Speed tuning in elementary motion detectors of the correlation type. Biological Cybernetics, 80(2), 109-116.

- Performance of 3 models



- Zanker, J. M., Srinivasan, M. V., & Egelhaaf, M. (1999). Speed tuning in elementary motion detectors of the correlation type. Biological Cybernetics, 80(2), 109-116.

- Optical Flow Method

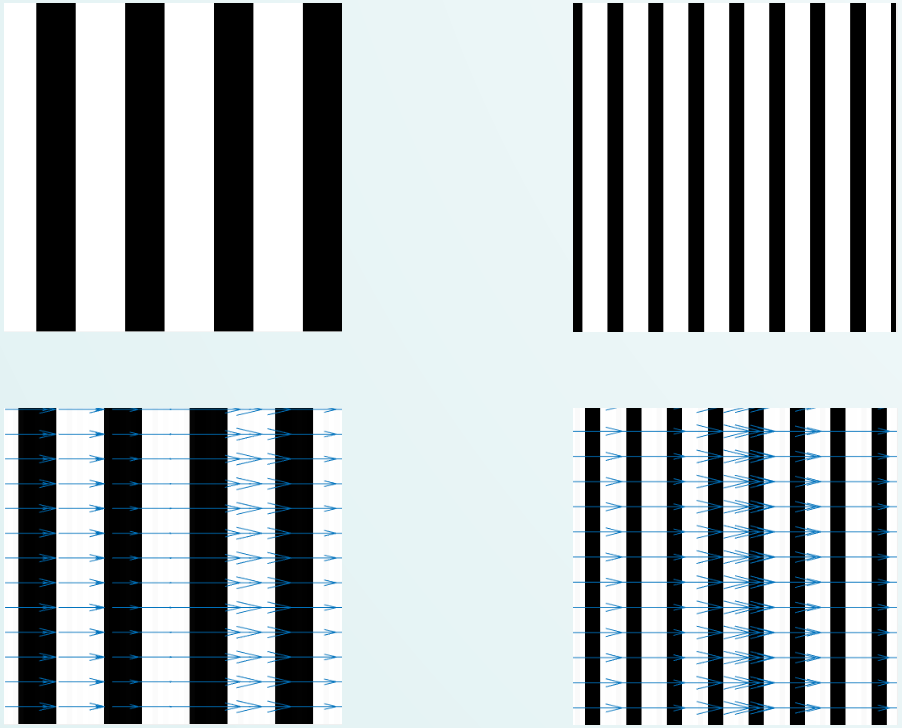
To compute the optical flow between two images, you must solve the following optical flow constraint equation:

$$I_x u + I_y v + I_t = 0$$

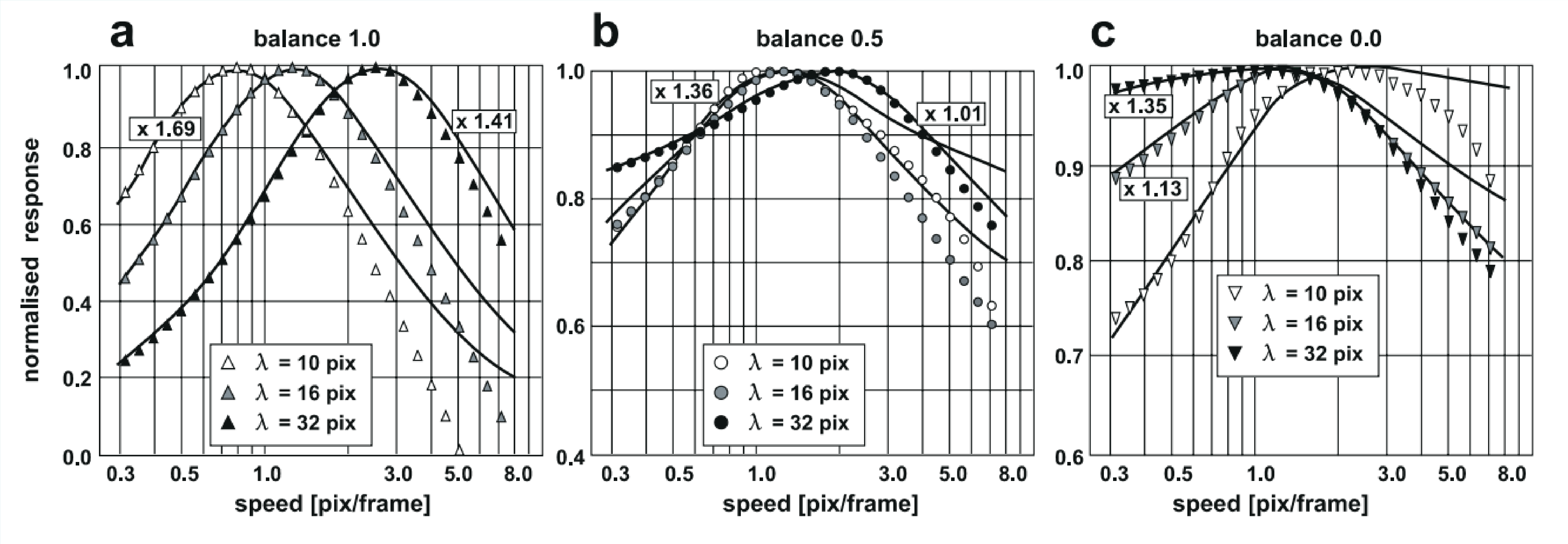
To solve *u* and *v* using the Horn-Schunck method:

1. Compute I_x and I_y using the Sobel convolution kernel, $[-1 \quad -2 \quad -1; \quad 0 \quad 0 \quad 0; \quad 1 \quad 2 \quad 1]$, and its transposed form, for each pixel in the first image.
2. Compute I_t between images 1 and 2 using the $[-1 \quad 1]$ kernel.
3. Assume the previous velocity to be 0, and compute the average velocity for each pixel using $[0 \quad 1 \quad 0; \quad 1 \quad 0 \quad 1; \quad 0 \quad 1 \quad 0]$ as a convolution kernel.
4. Iteratively solve for *u* and *v*.

- Grating experiments



- EMD models of different balance

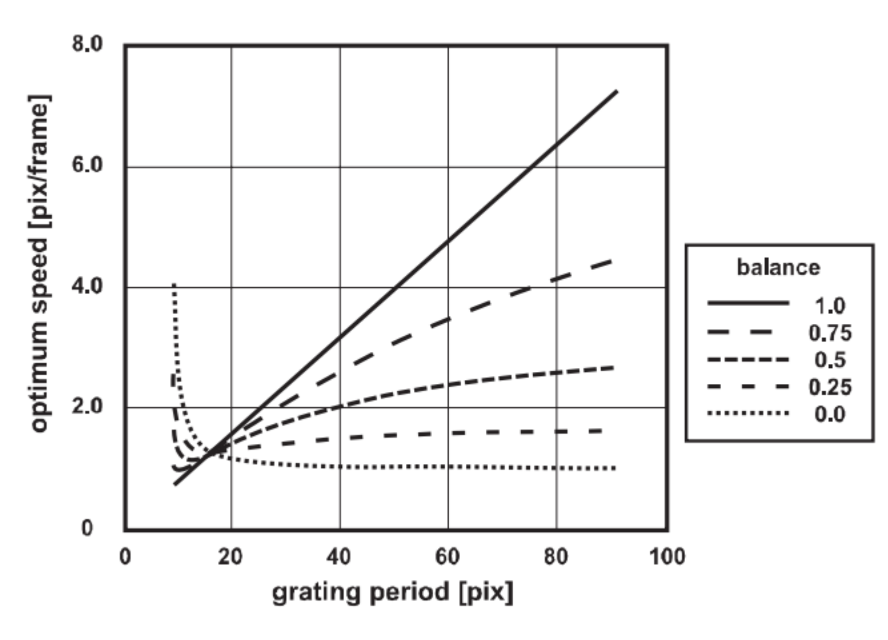


- Zanker, J. M., Srinivasan, M. V., & Egelhaaf, M. (1999). Speed tuning in elementary motion detectors of the correlation type. Biological Cybernetics, 80(2), 109-116.

- EMD model

Furthermore, Zanker tests the correlation models under different grating period to get a maximum responds :

- Fully balanced correlation model responds best to a characteristic temporal frequency rather than a characteristic speed.
- While half detector responds best to a preferred speed which means near the optimum speed the model is independent of spatial structure.

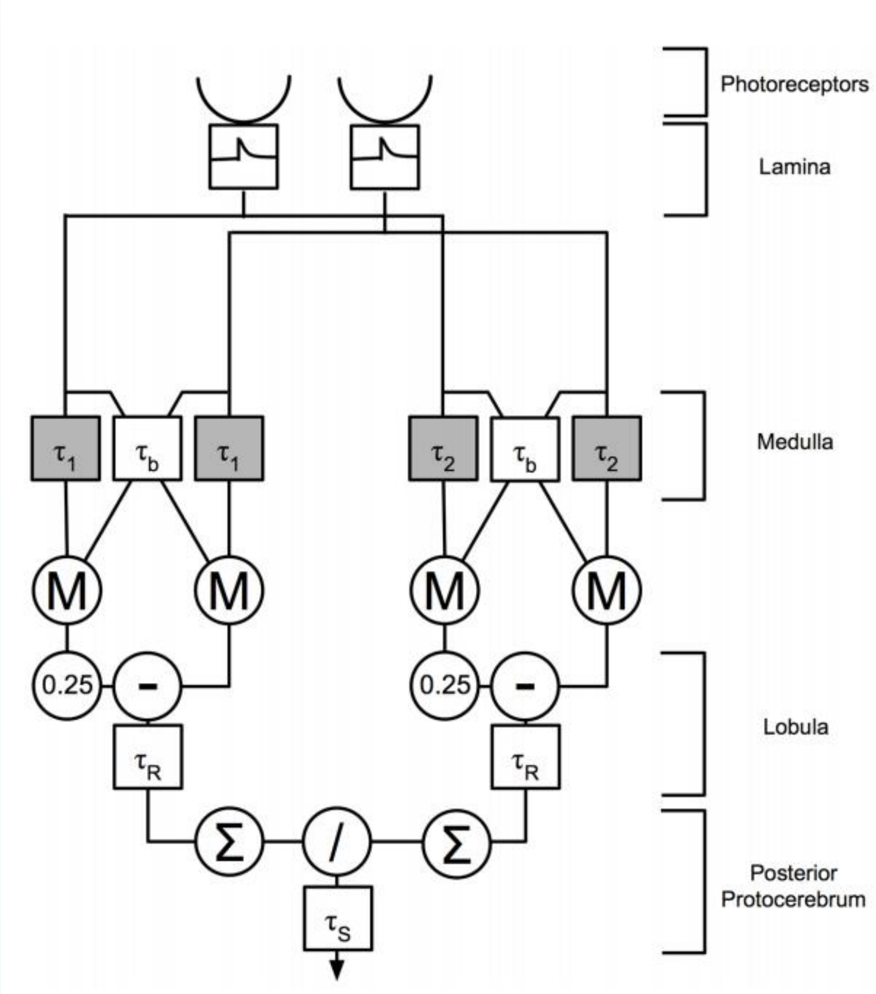


- Zanker, J. M., Srinivasan, M. V., & Egelhaaf, M. (1999). Speed tuning in elementary motion detectors of the correlation type. Biological Cybernetics, 80(2), 109-116.

- Angular Velocity Detector Model

An neurally based model is proposed upon EMD (Cope, 2016) to estimate angular velocity in the bee brain. The main idea is that:

- First it contains 2 partial balanced (0.25) EMD models with different time delays
- Second it uses the ratio of two outputs from 2 EMD to get a spatial independent angular velocity estimation.

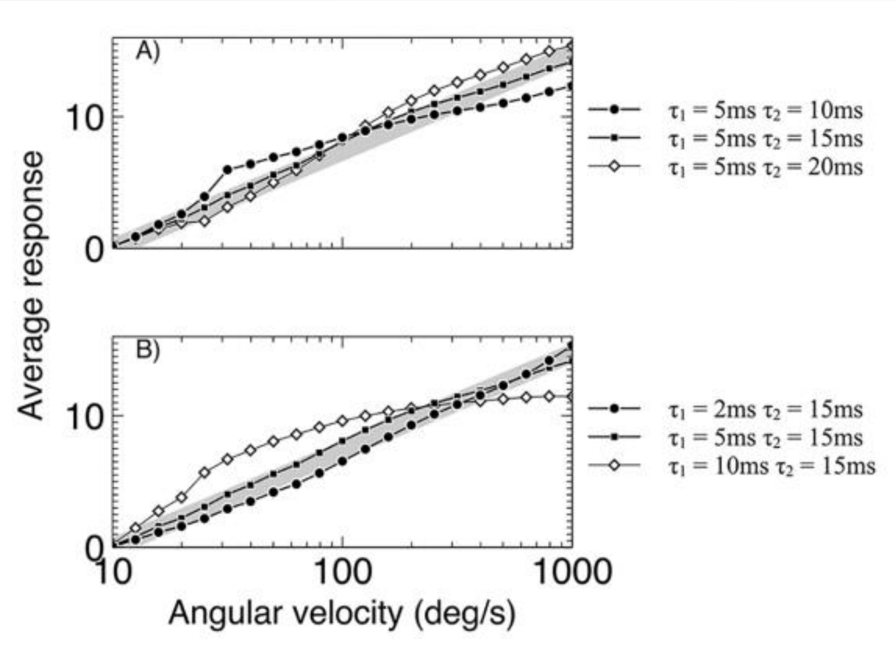


- Cope, A. J., Chelsea, S., Kevin, G., Eleni, V., & Marshall, J. A. R. (2016). A model for an angular velocity-tuned motion detector accounting for deviations in the corridor-centering response of the bee. PLOS Computational Biology, 12(5), e1004887.

- Angular Velocity Detector Model

➢ The parameters of time delayed is pivotal in this model. The authors get the delays by keeping one fixed to find the best value of the other.

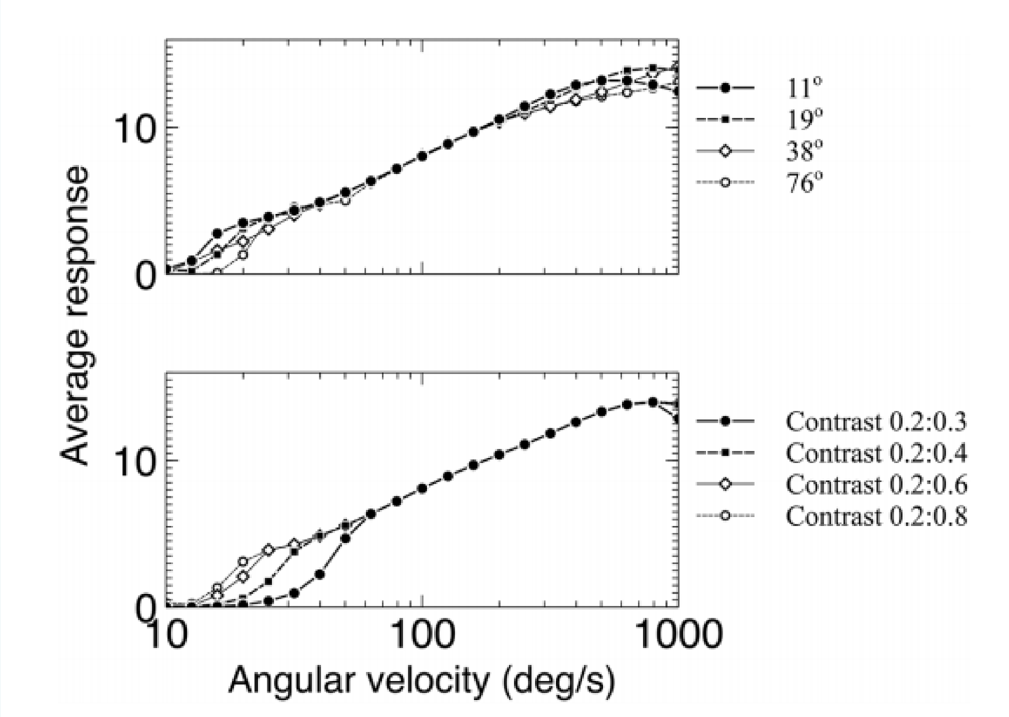
➢ The criterion for choosing best delays is whether the response have a log-linear relationship with angular velocity, which is consistent with most data sets of the experiment(8/13).



- Cope, A. J., Chelsea, S., Kevin, G., Eleni, V., & Marshall, J. A. R. (2016). A model for an angular velocity-tuned motion detector accounting for deviations in the corridor-centering response of the bee. PLOS Computational Biology, 12(5), e1004887.

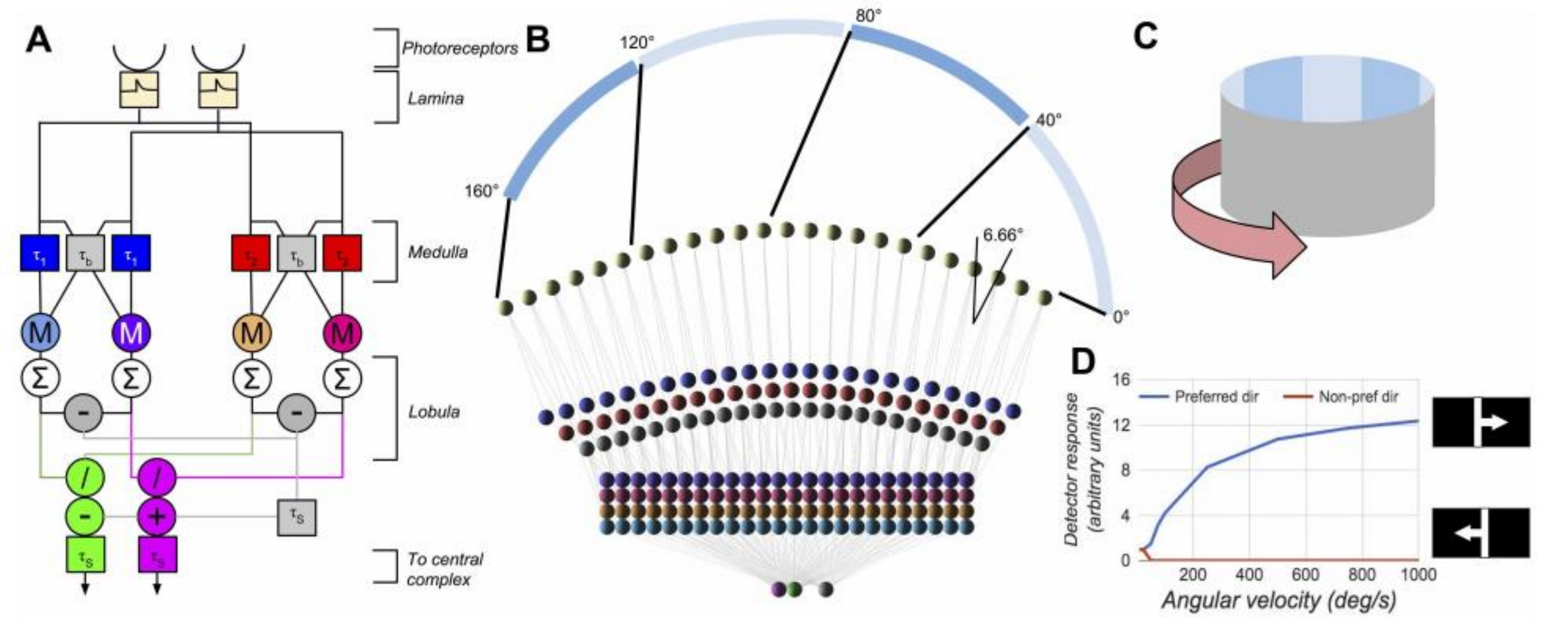
- Angular Velocity Detector Model

➢ The proposed model shows that response is almost independent of spatial structure and contrast when the angular velocity is not too high or to too low.



- Cope, A. J., Chelsea, S., Kevin, G., Eleni, V., & Marshall, J. A. R. (2016). A model for an angular velocity-tuned motion detector accounting for deviations in the corridor-centering response of the bee. PLOS Computational Biology, 12(5), e1004887.

- Angular Velocity Detector modified

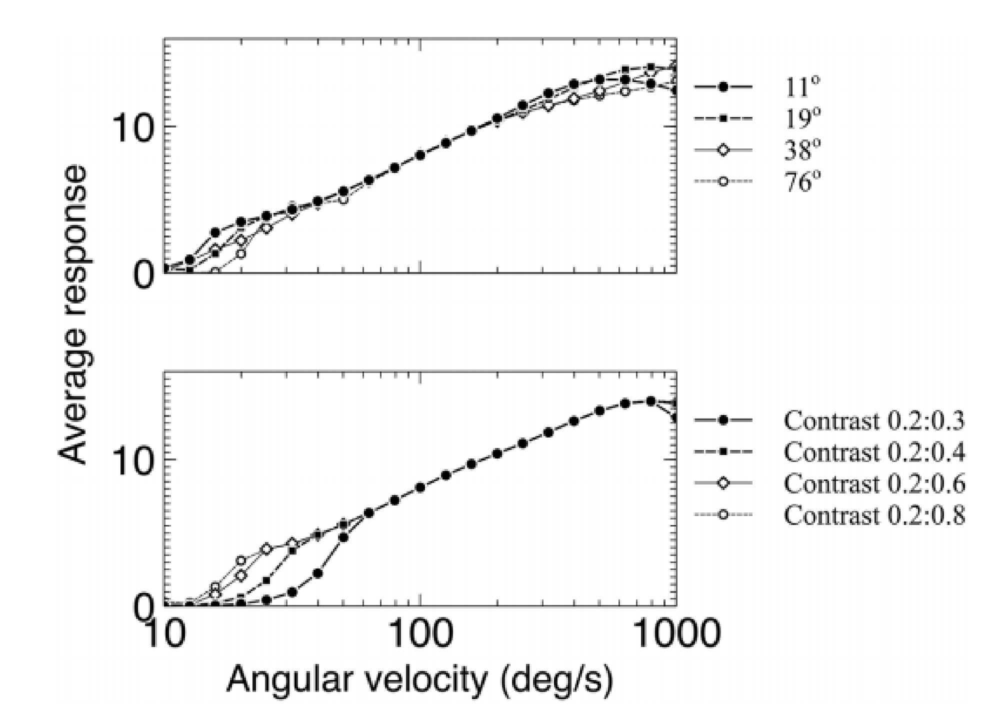


- Cope, A. J., Sabo, C., Vasilaki, E., Barron, A. B., & Marshall, J. A. (2017). A computational model of the integration of landmarks and motion in the insect central complex. Plos One, 12(2), e0172325.

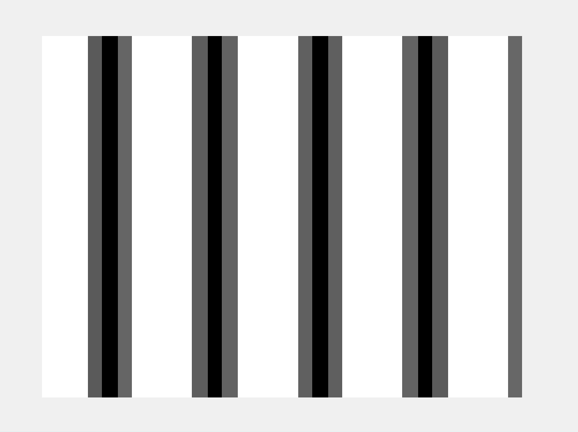
- Main doubts

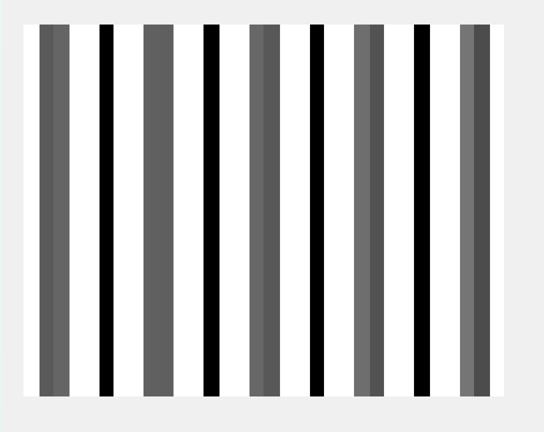
➢ Is there a mechanism for division in insect neural network? Why the ratio of two EMDs represents the angular velocity? If there is a mechanism for division, we can simply using optic flow to compute the speed exactly.

➢ Why the model can't maintain independent of grating period and contrast when the image go slower? In my view, it's easier for insect to estimate more accurate angular velocity when it moves a little slower.



- Grating Experiments: sinusoidal pattern





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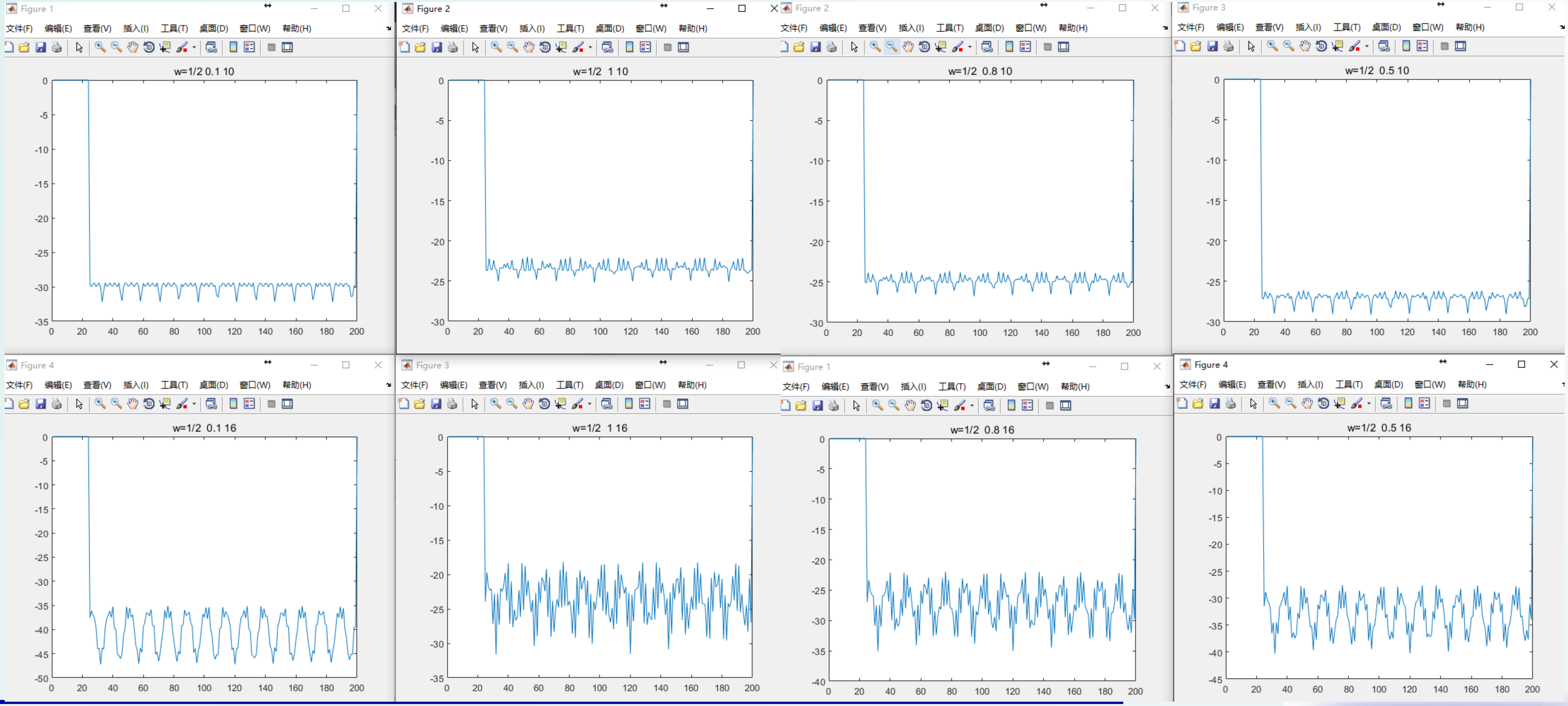
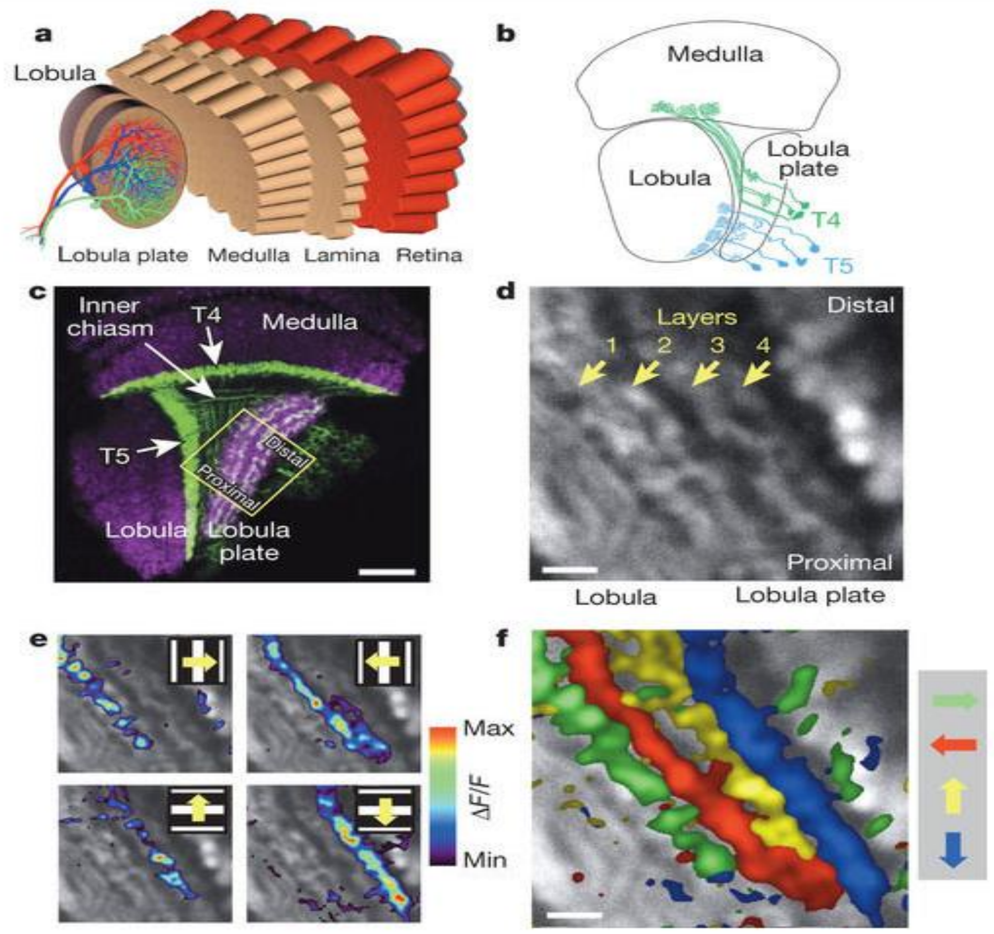
- Grating Experiments: different balance parameters



- 4 layers of lobula plate in EMD

Figure 1: Directional tuning and layer-specific projection of T4 and T5 cells.



- Maisak, M. S., Haag, J., Ammer, G., Serbe, E., Meier, M., & Leonhardt, A., et al. (2013). A directional tuning map of drosophila elementary motion detectors. Nature, 500(7461), 212.

- ON & OFF pathway of EMD

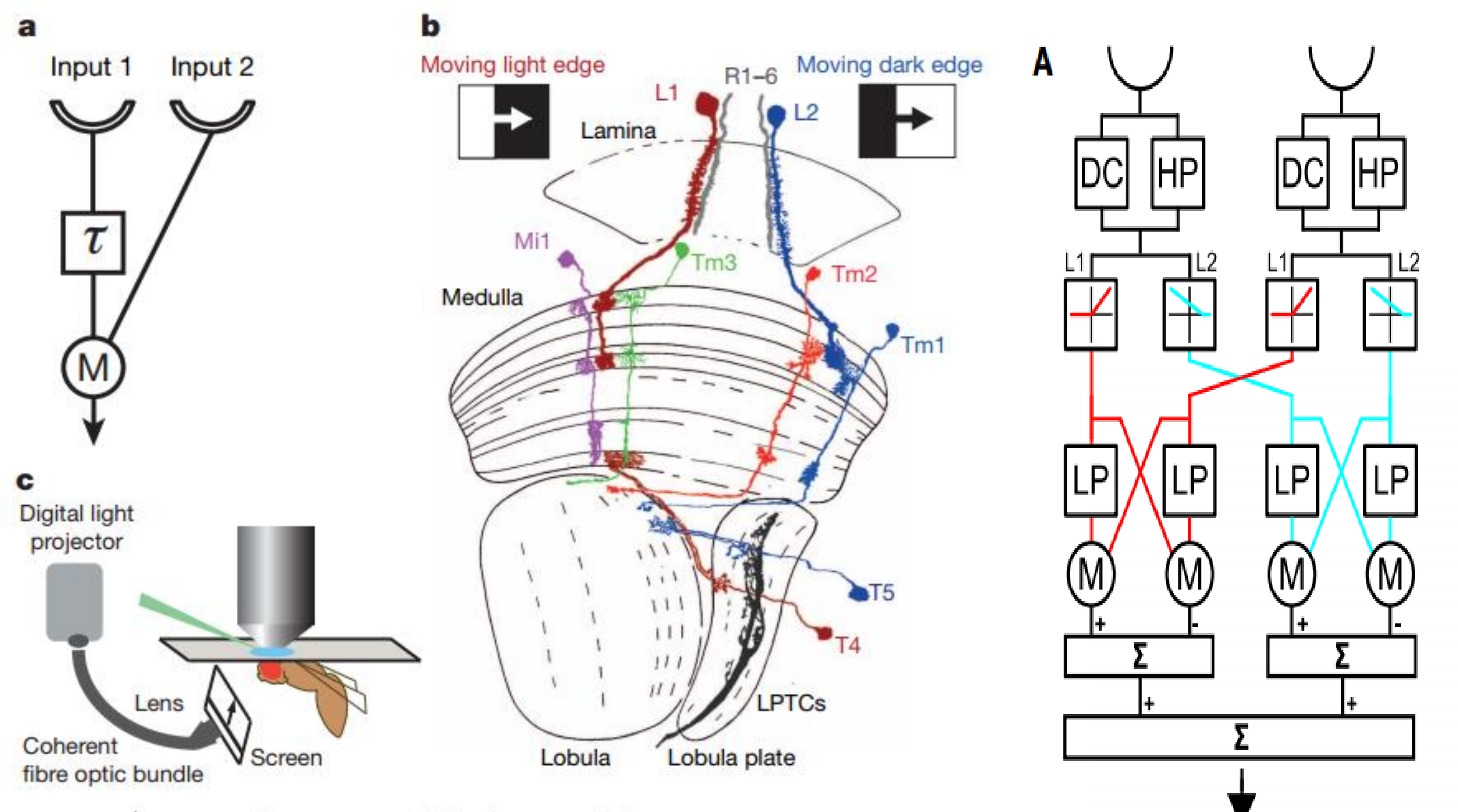


Figure 1 | Motion detection and the fly optic lobe.

- Eichner, H., Joesch, M., Schnell, B., Reiff, D. F., & Borst, A. (2011). Internal structure of the fly elementary motion detector. Neuron, 70(6), 1155-64.

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- Tm9 is required for Local Motion Detection

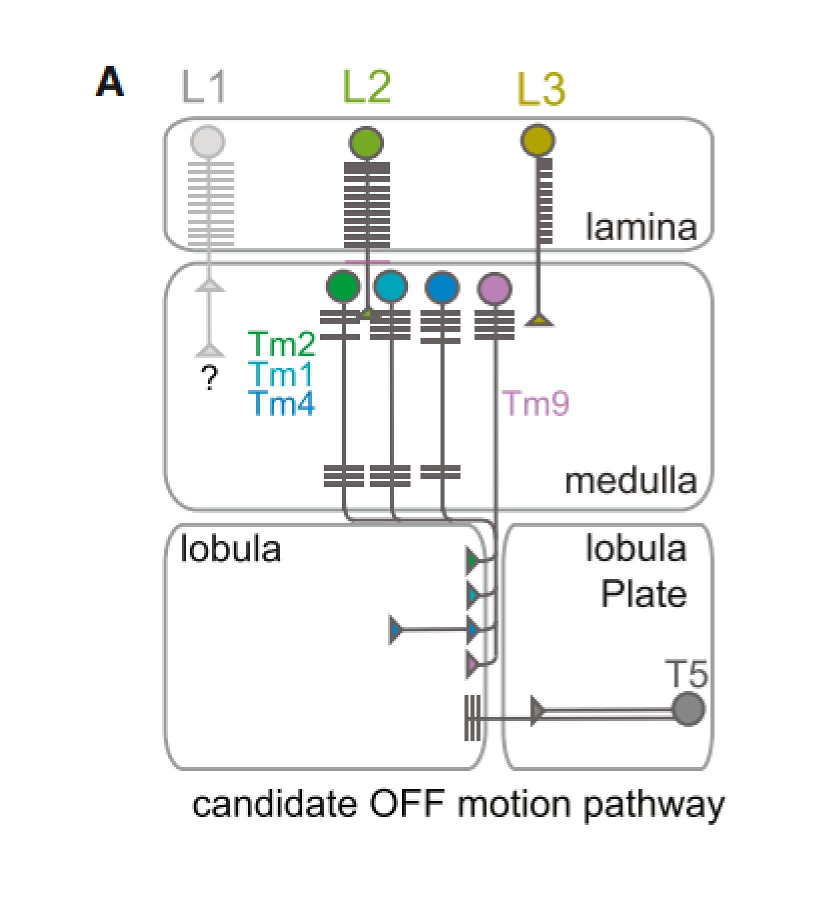
➢ Tm9 Is Critical for Moving OFF Edge Detection

➢ OFF Motion Detection Requires Inputs from L1, L3, and Tm9

➢ Tm9 Responses Require Inputs from Both L3 and L1

➢ Tm9 Neurons Respond to Visual Stimuli Across a Wide Visual Field

➢ Tm9 Is Broadly Required for Responses of Direction Selective T5



- Fisher, Yvette , Leong, Jonathan , C.S, & Sporar, et al. (2015). A class of visual neurons with wide-field properties is required for local motion detection. Current Biology Cb, 25(24), 3178.

- Artificial Compound eye CurvACE

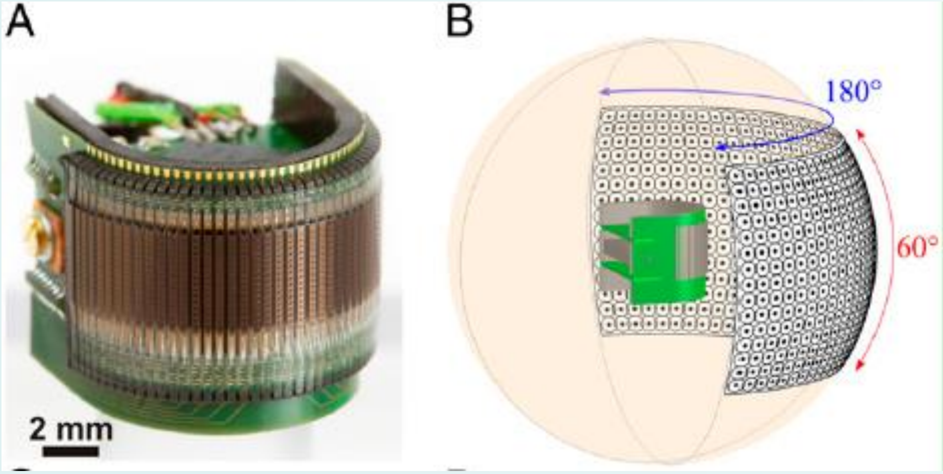


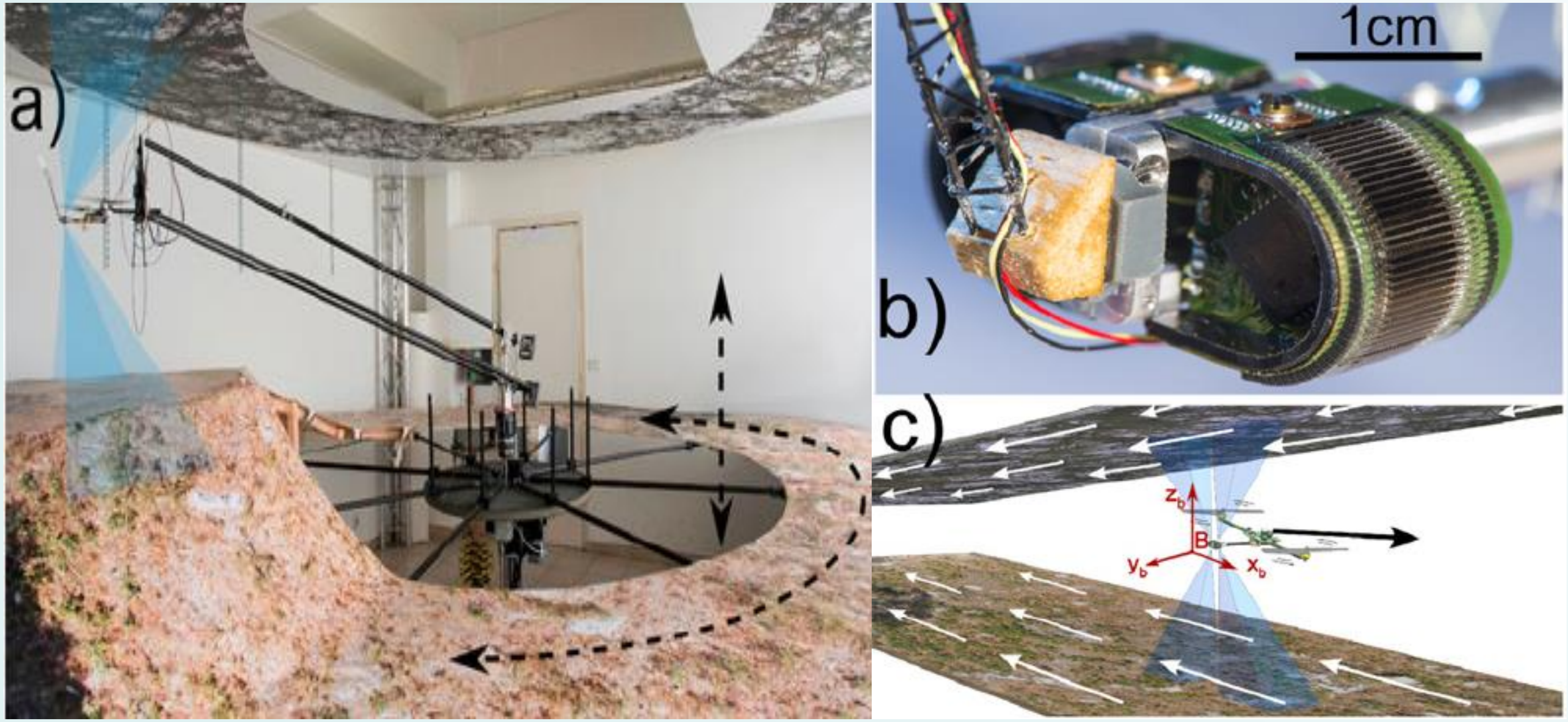
Table 1. Specifications of CurvACE prototype compared with the characteristics of the *Drosophila melanogaster* compound eye

	CurvACE	*Drosophila* eye [Ref(s).]
Number of ommatidia	630	600–700
Facet diameter, μm	172	16 (42)
Eye diameter, mm	12.8	0.36 (42)
Facet diameter/eye diameter, %	1.3	4.4
Interommatidial angle, $\Delta\varphi$; deg.	~4.2	~4.7–5.5 (42)
Acceptance angle, $\Delta\rho$; deg.	4.2	~4.5 (24)
FOV, deg.	180 × 60	160 × 180 (43)
Signal acquisition bandwidth, Hz	300	<100 (28)
Adaptability to illuminance	Yes	Yes (4)
Crosstalk prevention	Yes	Yes (24)

deg., degree.

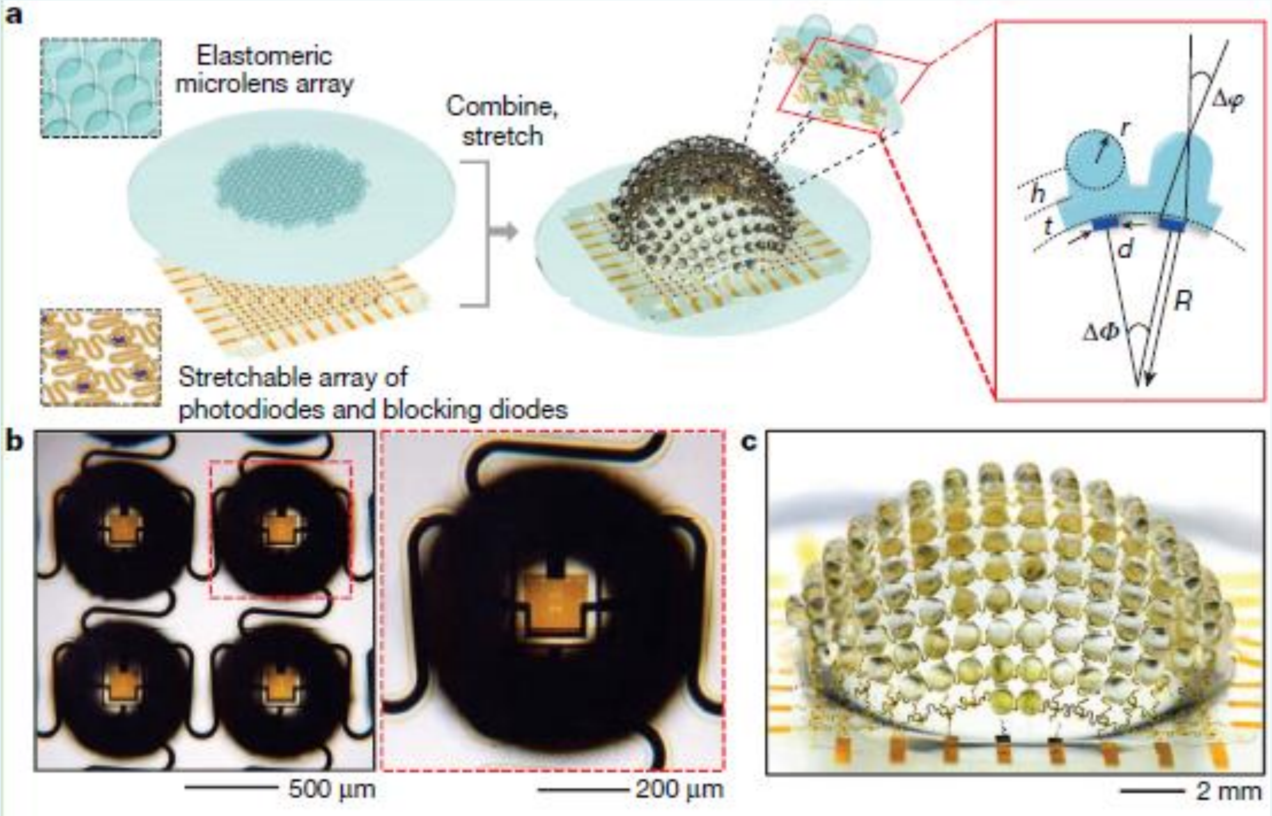
- Floreano, D., Pericet-Camara, R., Viollet, S., Ruffier, F., Brückner, A., & Leitel, R., et al. (2013). Miniature curved artificial compound eyes. Proceedings of the National Academy of Sciences of the United States of America, 110(23), 9267.

- Artificial Compound eye CurvACE



- Expert, F., & Ruffier, F. (2015). Flying over uneven moving terrain based on optic-flow cues without any need for reference frames or accelerometers. Bioinspiration & Biomimetics, 10(2), 026003.

- Artificial hemispherical compound eye



- Song, Y. M., Xie, Y., Malyarchuk, V., Xiao, J., Jung, I., & Choi, K. J., et al. (2013). Digital cameras with designs inspired by the arthropod eye. Nature, 497(7447), 95-9.

- Artificial compound eye

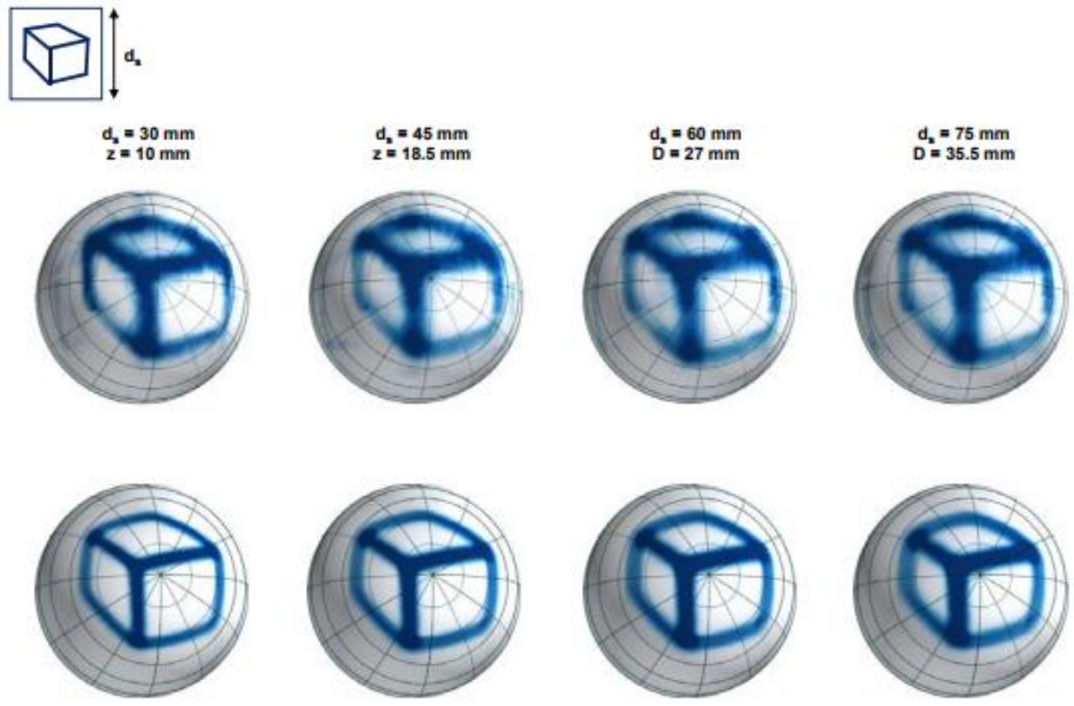


Figure S23. (top) Images of a 3D box captured at four different distances but with the same angular size. The sizes of object panels proportionally increase as the distance increases. (bottom) corresponding simulation images

- Song, Y. M., Xie, Y., Malyarchuk, V., Xiao, J., Jung, I., & Choi, K. J., et al. (2013). Digital cameras with designs inspired by the arthropod eye. Nature, 497(7447), 95-9.

Thanks !