Binocular integration as nonlinear mixing: how binocular neurons in primary visual cortex preserve eye-specific information for downstream visual processing

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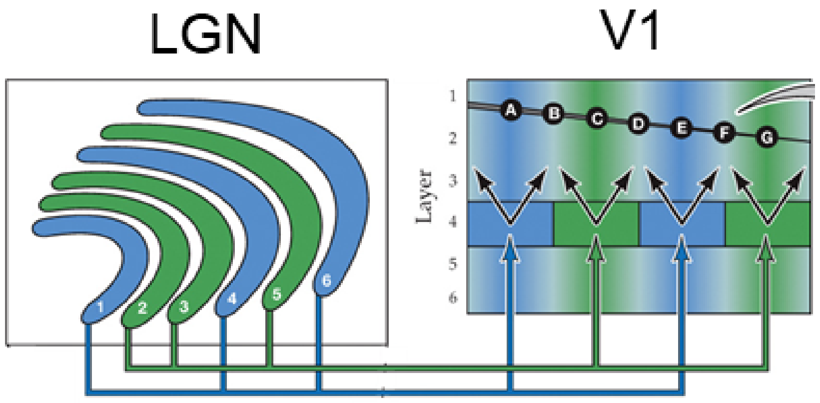
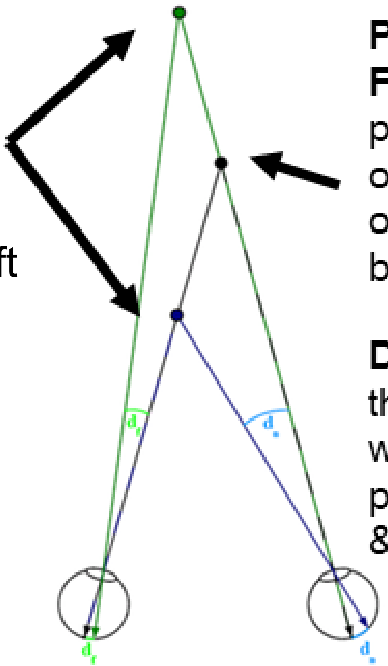
Binocular integration occurs in primary visual cortex, and is believed to involve disparity information



From Purves et al. Neuroscience

How can information from both eyes be meaningfully combined without sensitivity to binocular disparity?

Other points in visual space **don't project** onto matching points of the left and right retina

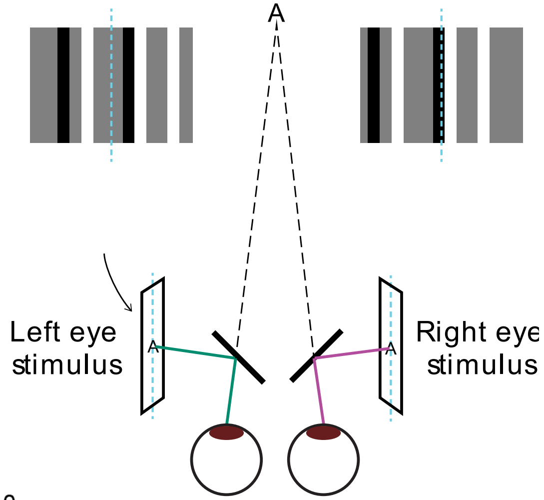


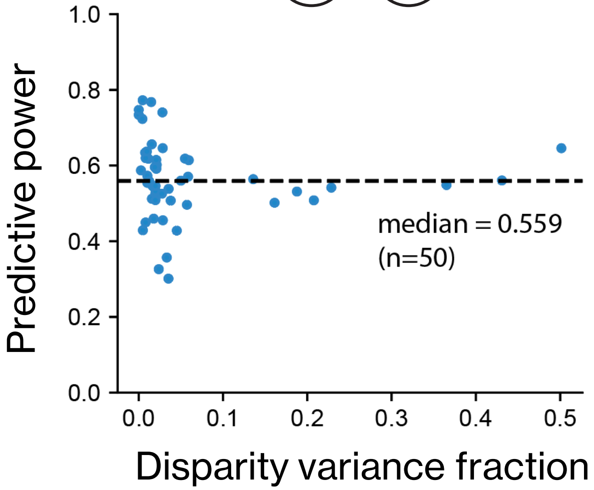
Point of Fixation, projects onto center of retina in both eyes.

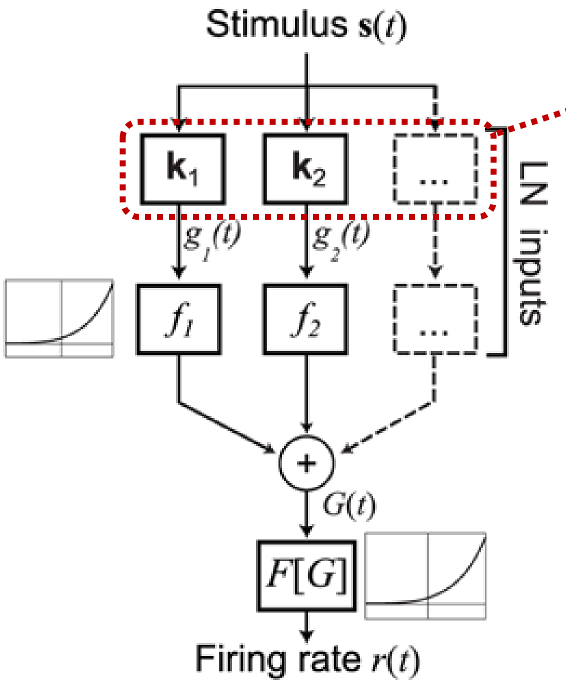
Disparity is the difference where these points fall on L & R eye

We can run simulations with well-fit binocular convolutional models to understand these V1 neurons

Based on data from Bruce Cumming (NIH) [1]

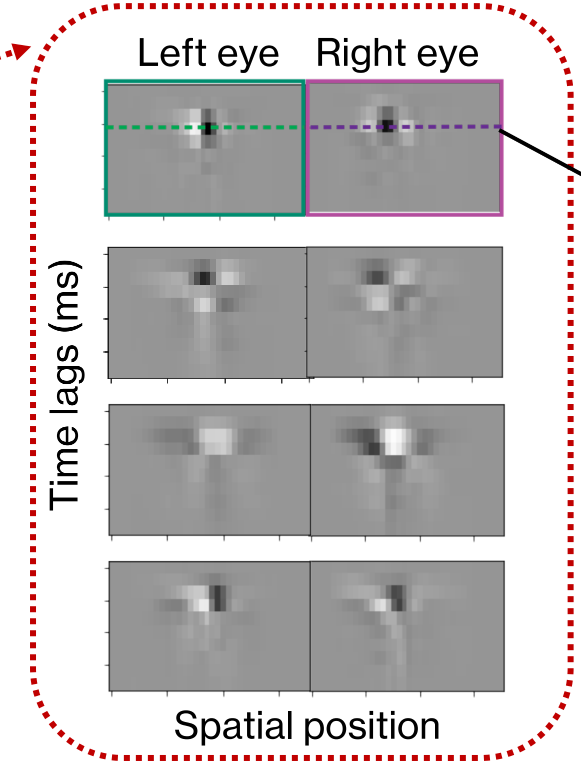


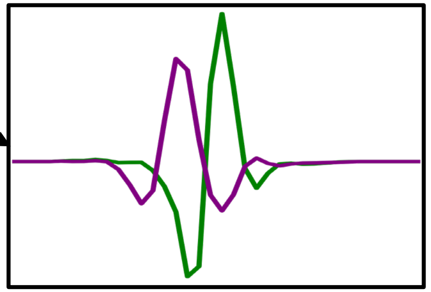




Binocular Convolutional Model (BCM) [2]

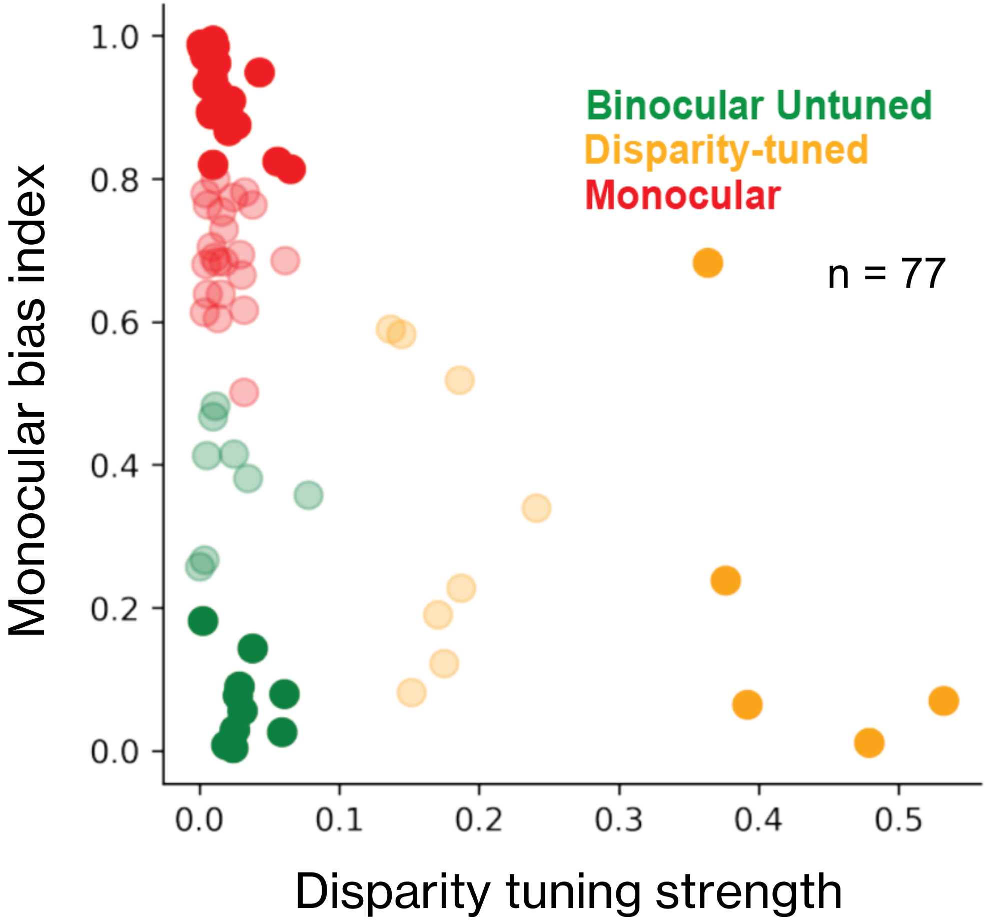
Spatiotemporal filters of a disparity-tuned neuron





See SFN 2021 Poster Presentation P479.06

Only a fraction of binocular neurons in V1 are selective to disparity

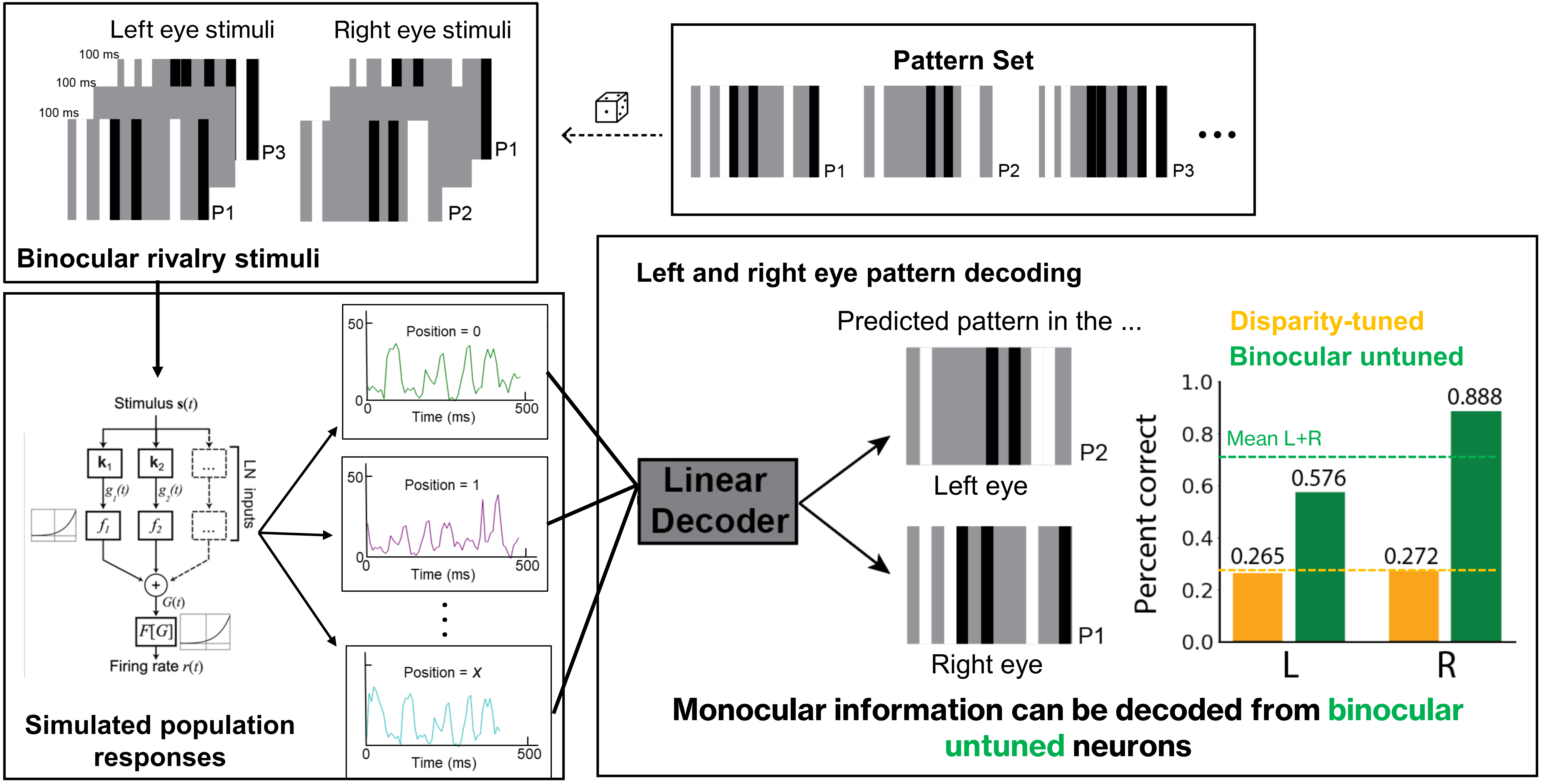


Hypothesis: Monocular information (i.e., info about the image in a specific eye) is carried by binocular neurons that are not tuned to disparity (“**binocular untuned**” neurons) and can be decoded at the population level [3].

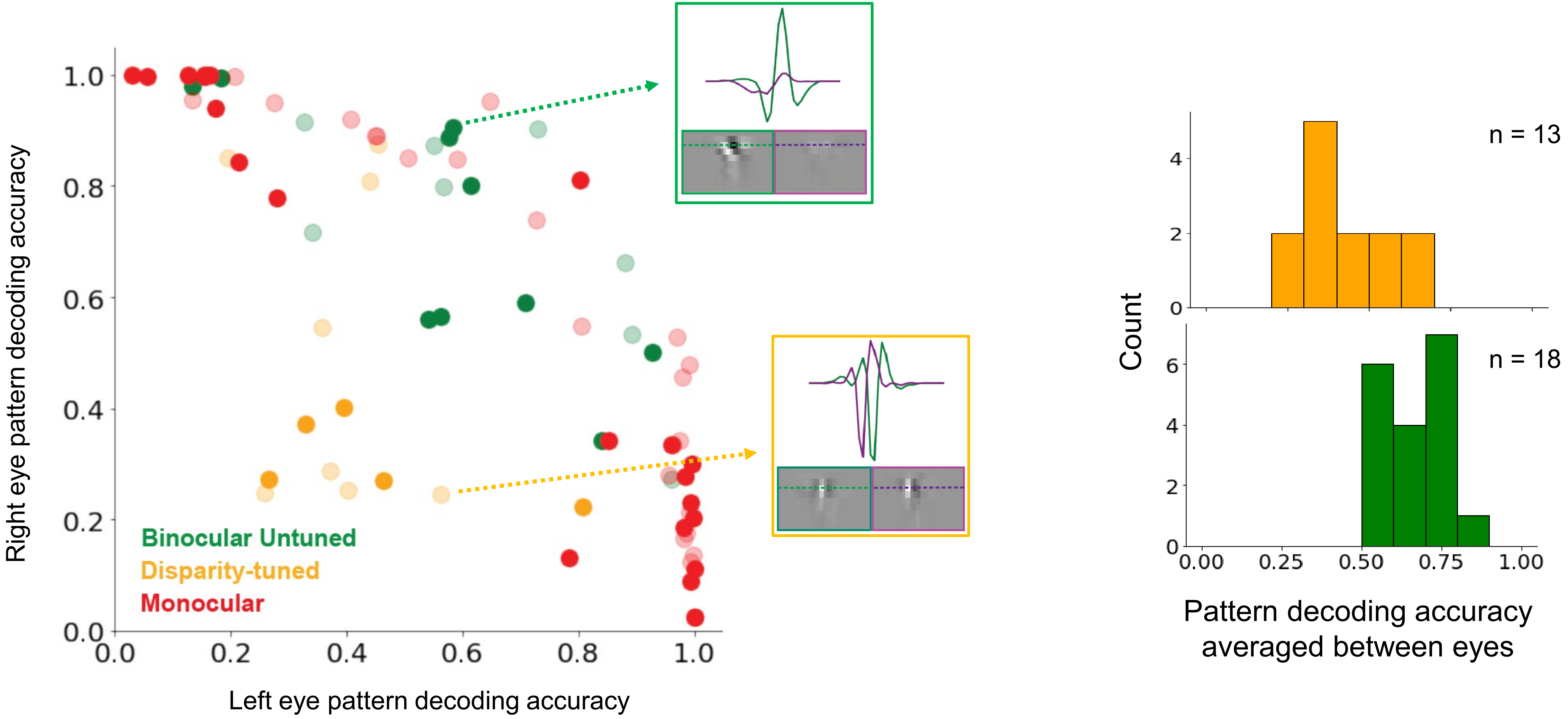
Corollary: Binocular integration generally occurs through nonlinear mixing [4], which will also facilitate more sophisticated computations in depth [5-7]

$$Monocular\ Bias\ Index = abs\left(\frac{var(R_R) - var(R_L)}{var(R_R) + var(R_L)}\right)$$

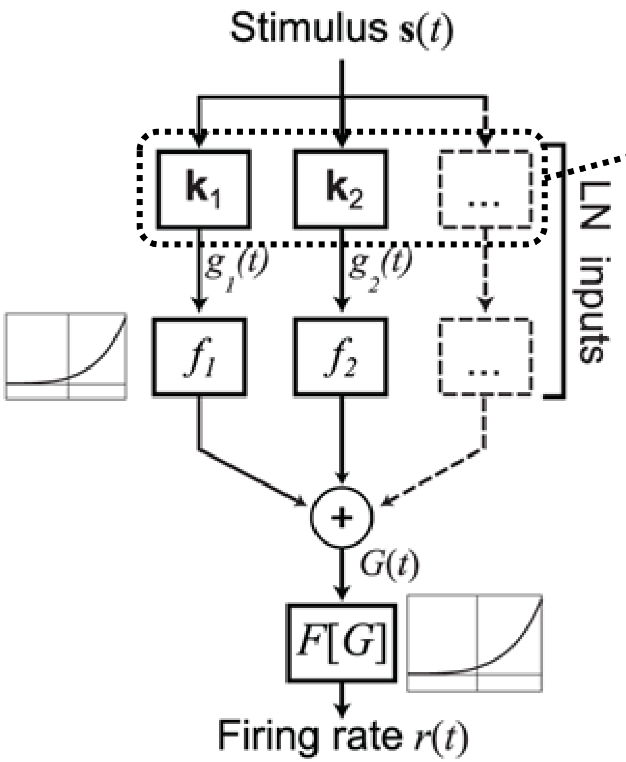
Binocular rivalry simulation

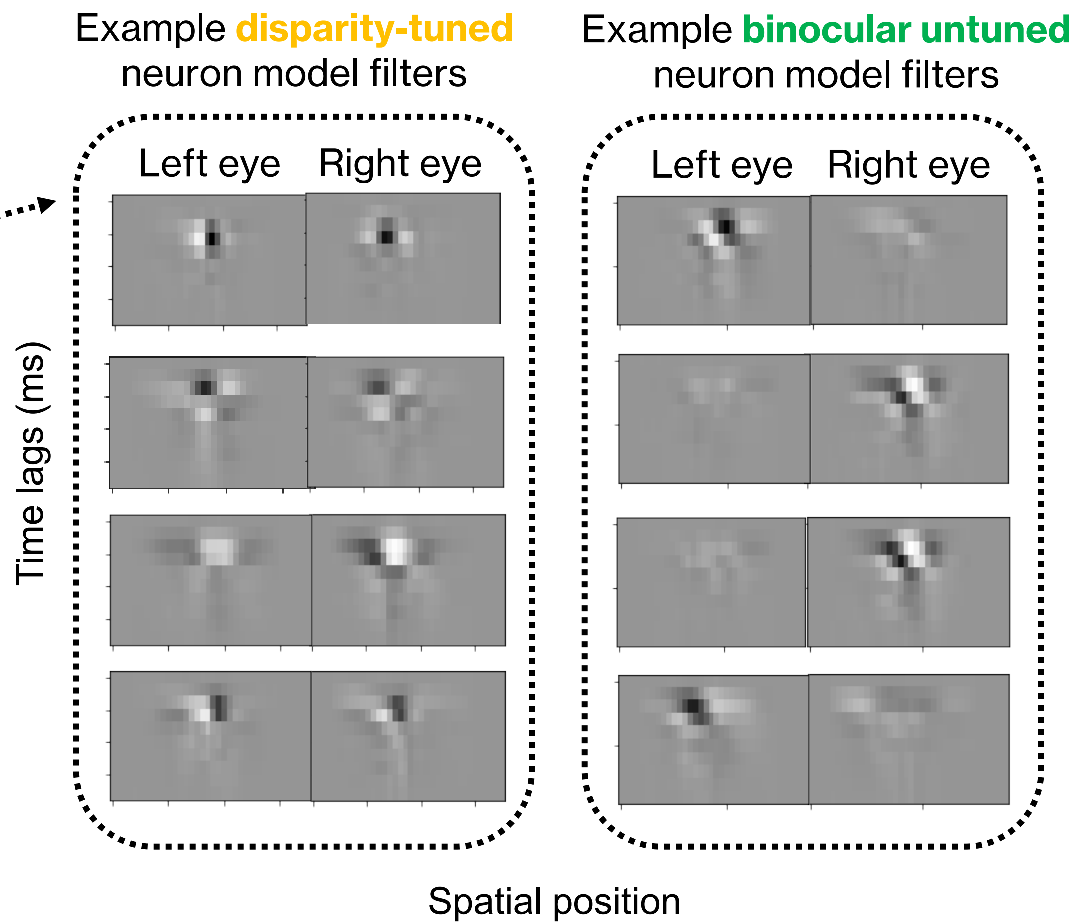


Binocular untuned neurons encode more monocular information than disparity-tuned neurons



Binocular untuned neurons nonlinearly mix left and right eye information





$$f(\mathbf{k}_L \cdot \mathbf{s}_L + \mathbf{k}_R \cdot \mathbf{s}_R) \quad \textbf{(1)}$$

Disparity-tuned subunit:
linear combination of L & R eye information

$$f(\mathbf{k}_L \cdot \mathbf{s}_L) + f(\mathbf{k}_R \cdot \mathbf{s}_R) \quad \textbf{(2)}$$

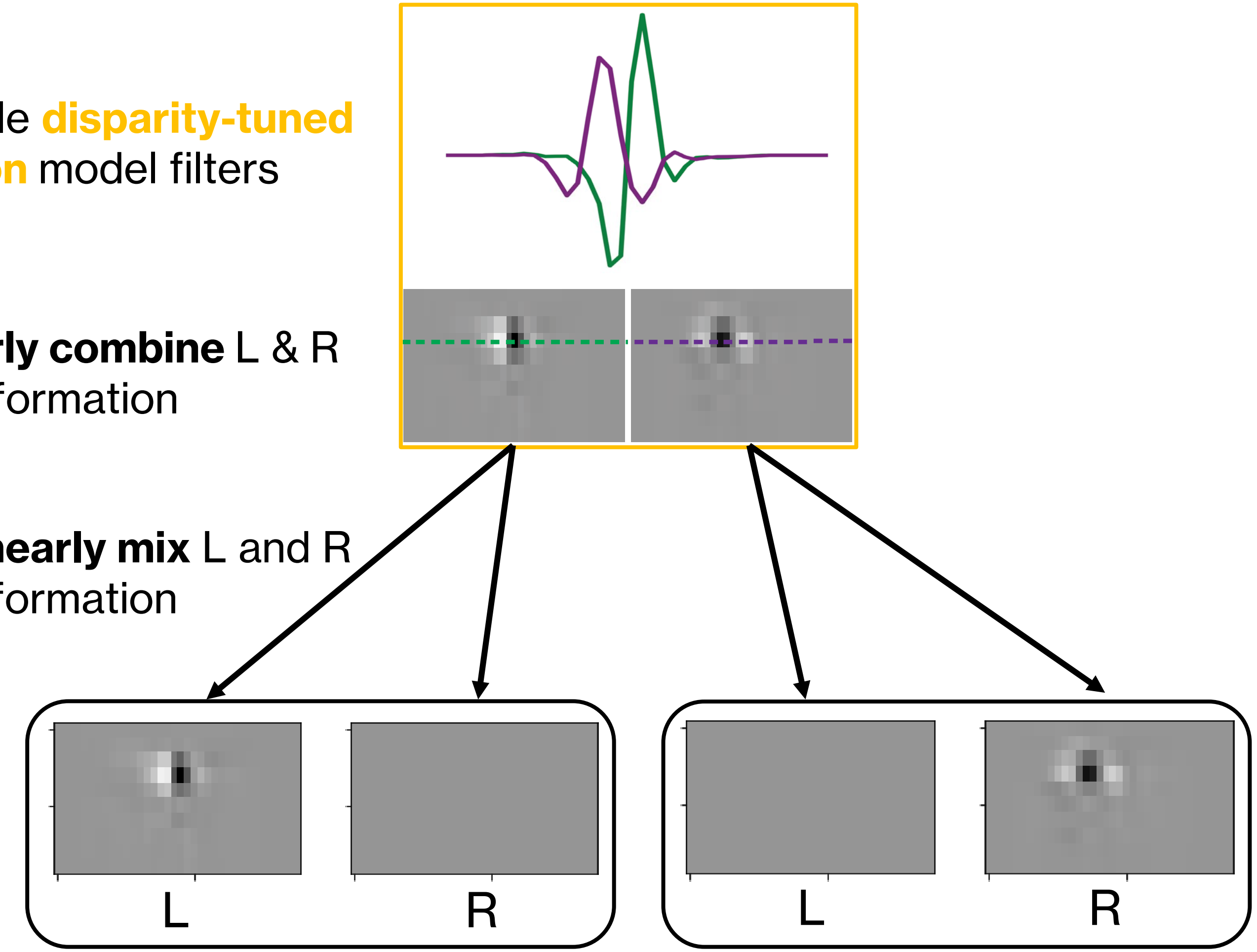
Binocular untuned:
nonlinear mixing of L & R eye information

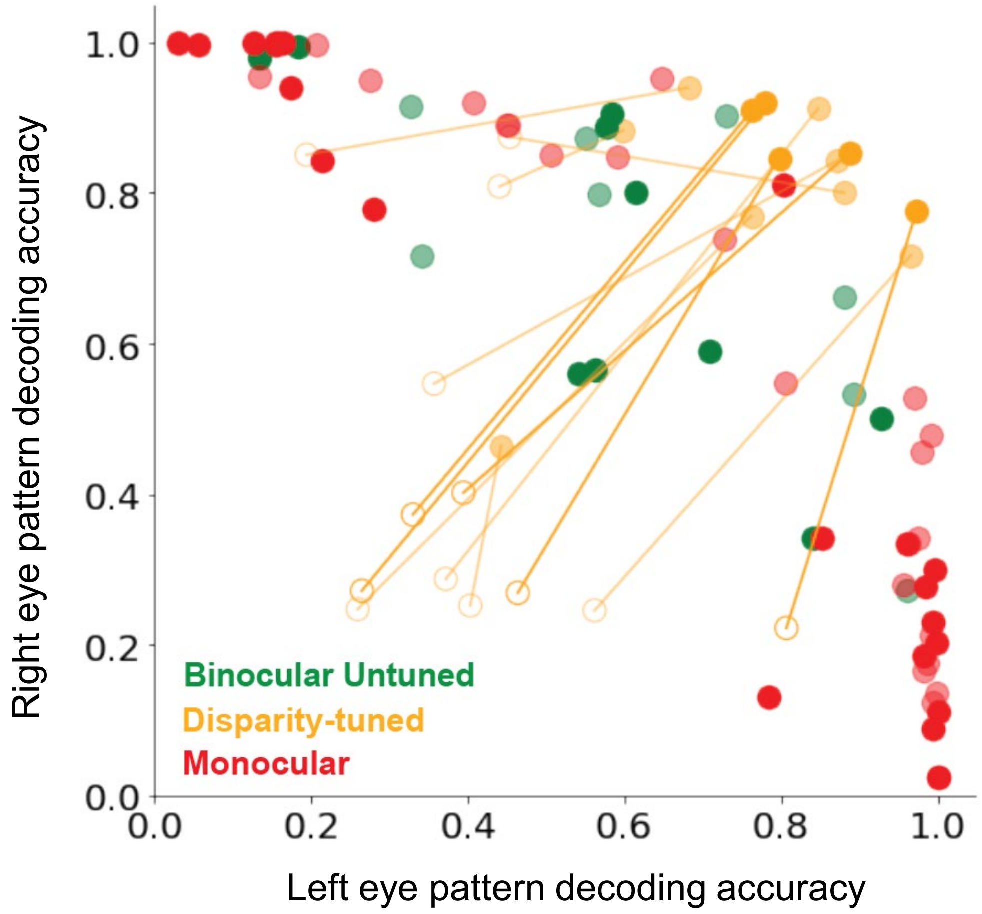
Converting disparity-tuned neurons into binocular untuned neurons rescues monocular information

Sample **disparity-tuned neuron** model filters

Linearly combine L & R eye information

Nonlinearly mix L and R eye information





Nonlinear mixtures preserve information at population level

Conclusions

- Most V1 neurons are binocular but combine left and right eye information irrespective of binocular disparity.
- Binocular neurons that are insensitive to disparity (“binocular untuned” neurons) preserve eye-specific stimulus information and is extractable by population decoding; no separate eye channels are needed to preserve eye-specific information [3].
- Binocular untuned neurons represent “nonlinear mixtures” of left and right-eye information and may be used for flexible downstream decoding of more complex conjunctions of features [4], such as facilitating sensitivity to three-dimensional motion [5-7].

References

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