Retistruct: A package to reconstruct flattened retinae

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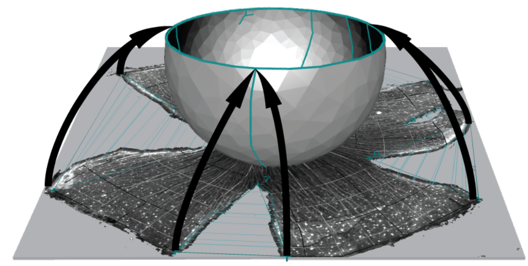
Background & problem

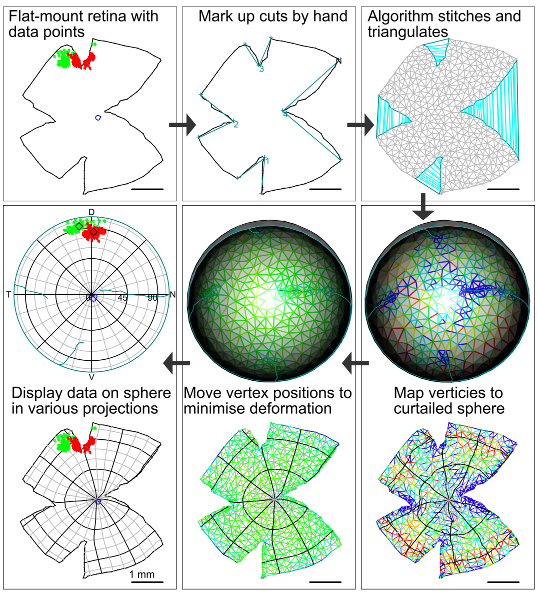
The concept of topographic mapping is central to the understanding of the visual system at many levels, from the developmental to the computational. It is important to be able to relate different coordinate systems, e.g. maps of the visual field and maps of the retina. Retinal maps are frequently based on flat-mount preparations. These use dissection and relaxing cuts to render the quasi-spherical retina into a 2D preparation. The variable nature of relaxing cuts and associated tears limits quantitative cross-animal comparisons.

A solution: retinal reconstruction



Our "Retistruct" algorithm reconstructs retinal flat-mounts by mapping them into a standard, spherical retinal space.

Algorithm

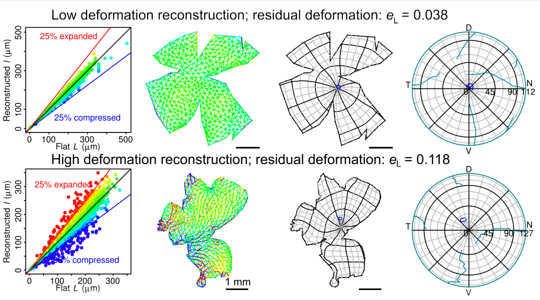


Physically-inspired deformation depends on lengths L_i and l_i of corresponding connections $i \in \mathscr{C}$ in flattened and spherical retina:

$$e_{\mathrm{L}} = \sqrt{\frac{1}{2|\mathscr{C}|\bar{L}} \sum_{i \in \mathscr{C}} \frac{(l_i - L_i)^2}{L_i}}$$

While moving vertices, extra term to prevent triangles flipping.

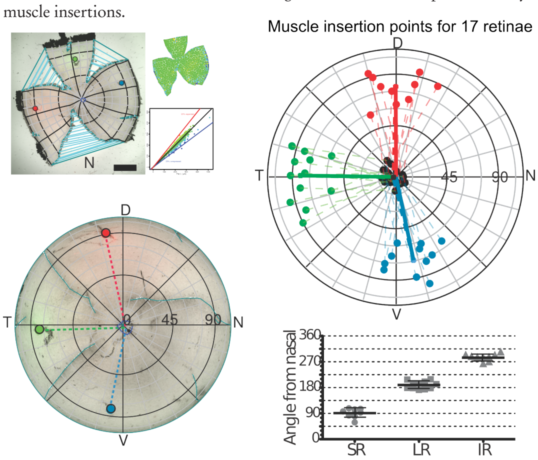
Low & high deformation reconstructions



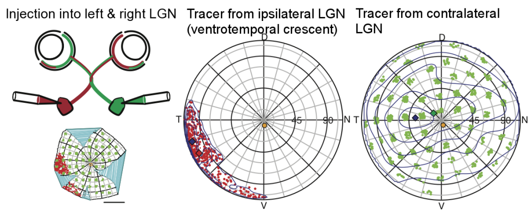
- Algorithm applied to 297 flat-mounted retinae
- 288 reconstructed successfully
- 7 failed due to, as-yet unresolved, software problems
- 2 rejected because of unsatisfactory reconstructions ($e_{\mathrm{L}} > 0.2$)

Eye muscle insertions

Orient the retina relative to the nictitating membrane and compare this to eye muscle insertions.

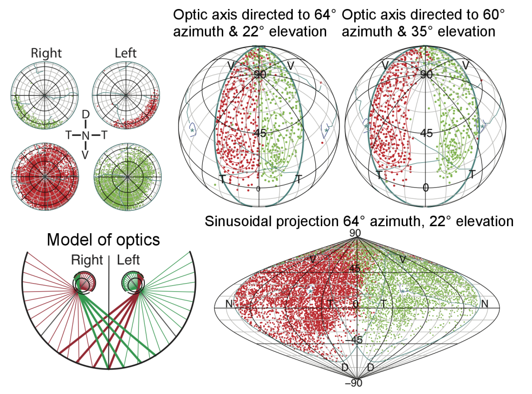


Projections to LGN



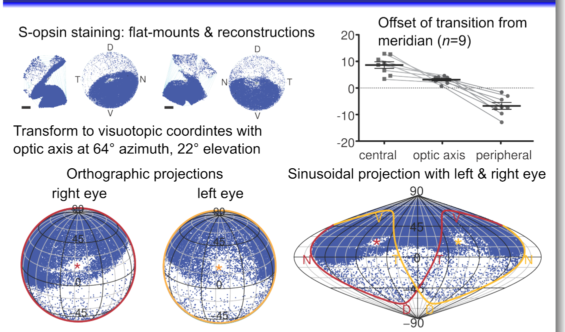
Kernel Density Estimates and Kernel Regression estimates computed using Fisherian density (Fisher, 1953); bandwidth determined by cross-validation.

Conversion to visuotopic coordinates



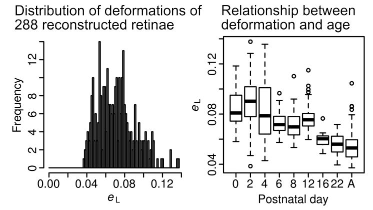
- When retinal distribution of the ipsilateral ventrotemporal crescent neurons is transformed into visuotopic space using the optic axis coordinates of 64° azimuth and 22° elevation (Oommen and Stahl, 2008), the decussation line lines up with the vertical meridian.
- Optic axis pointing to optic disc coordinates of 60° azimuth and 35° elevation (Dräger, 1978) ⇒ visual mismatch between decussation lines.

S-opsin distribution



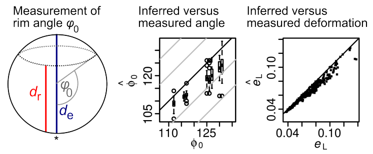
Optic axis orientation $(64°, 22°)$ ⇒ dorsoventral boundary for S-opsin expressing cones closely matches the horizontal meridian (Haverkamp et al., 2005).

Deformation statistics



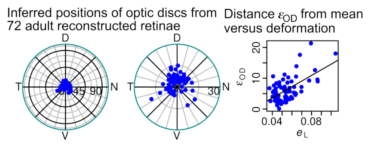
More residual deformation in younger, more delicate retinae.

Effect of rim angle



- To determine the rim angle of mouse eyes at varying stages of development, measure the distance d_e from the back of the eye to the front of the cornea and the distance d_r from the back of the eye to the edge of the retina.
- Rim colatitude (angle measured from the retinal pole) $\varphi_0 = \arccos(1 - 2d_r/d_e)$
- Alternative approach: infer, for each retina, the rim angle $\hat{\varphi}_0$ that minimises the deformation.
- Maximum decrease in deformation is 19.1%; mean improvement being 7.2%.
- ⇒ improvement does not justify adding refinement of the rim angle to the algorithm.

Validation using optic disc locations



⇒ the algorithm can estimate the position of a point on the intact retina to within 8° of arc (3.6% of nasotemporal axis).

Retistruct package

- Reconstruction and transformation methods implemented in R and will be freely available as an R package from http://retistruct.r-forge.r-project.org/
- Tested on GNU/Linux, but should also work in MacOS and Windows.
- Data formats: coordinates of data points and retinal outline from an in-house camera-lucida setup, or bitmap images with an outline marked up in ImageJ ROI format.
- GUI interface to facilitate the marking-up of retinae and displaying reconstructed retinae.

References

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Fisher, R. *Proc. R. Soc. Lond., A* **217**:295–305, 1953
Haverkamp, S., Wässle, H. et al. *J. Neurosci.* **25**:5438–5445, 2005
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