Geometric Constraints in the Development of Primate Extrastriate Visual Cortex

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Background & Research Question

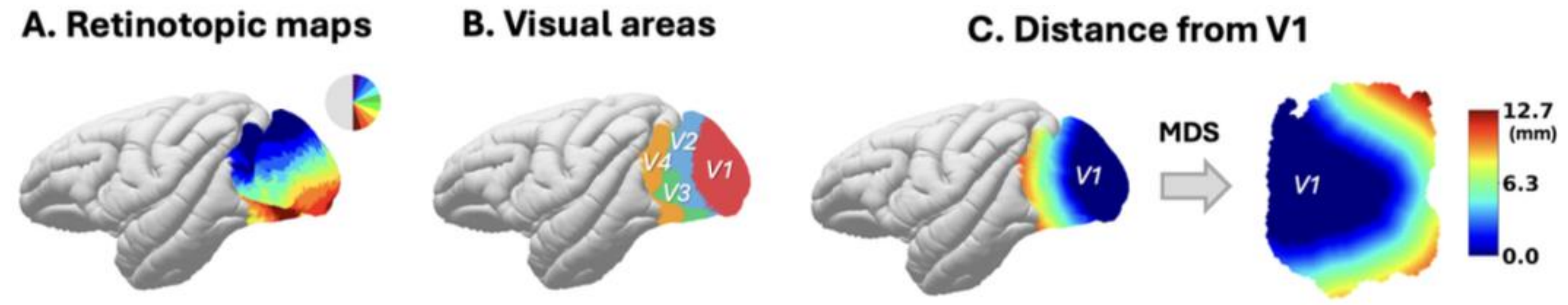
- Topographically organized input from the lateral geniculate nucleus establishes V1 as an early retinotopic anchor for visual cortex development, but how this organization extends to form multiple higher-order maps remains unclear.
- Because cortical connections weaken with distance along the folded cortical sheet, cortical geometry may constrain extrastriate map organization.[1]

Can V1-anchored, distance-dependent growth generate retinotopy, including areal borders and individual variability, without predefined area boundaries?

Model Setup

Cortical Surface: NIMH Macaque Template (NMT)[2]
Geometry: Cortical geodesic distances embedded in 2D using MDS

Input: Cortical geometry + fMRI-defined V1 retinotopy[3]
Output: Predicted V2-V4 polar angle and eccentricity
Metrics: Spearman's ρ and retinotopic error Δ



Growth Algorithm[5]

Model intuition: Projections grow where V1 and extrastriate nodes are coactive, but high-degree V1 nodes are penalized so growth does not collapse onto a few sources.

Spatial similarity

Distance-dependent similarity favors nearby or jointly activated cortical neighborhoods.

$$s(u,v) = \exp\left(-\sqrt{\left(\frac{d_R(u,v)}{\sigma_R}\right)^2 + \left(\frac{d_T(u,v)}{\sigma_T}\right)^2}\right)$$

Degree competition

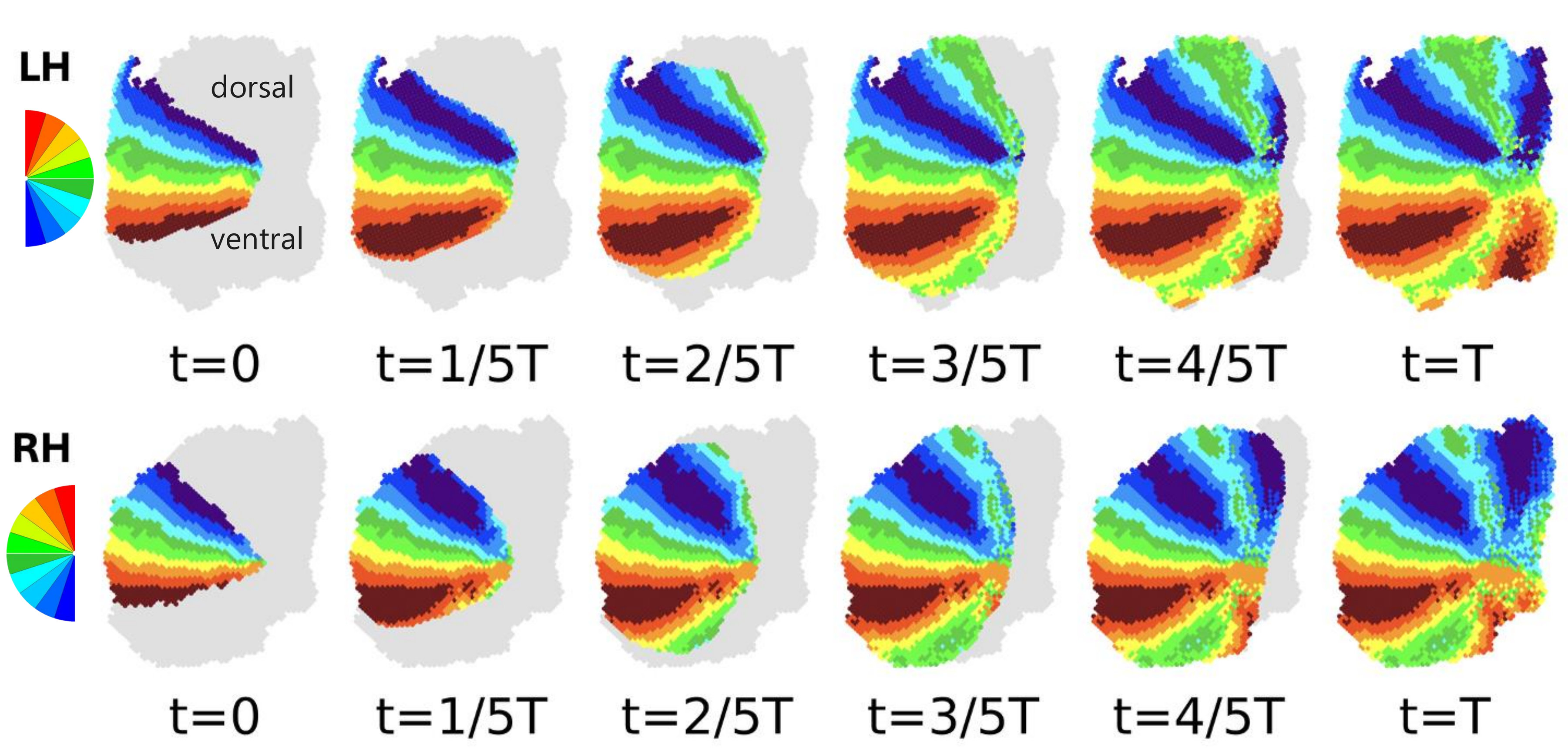
V1 nodes with many outgoing projections become less likely to form new edges.
k_u: out-degree of V1 node u

$$r(u) = \frac{1}{k_u + 1}$$

Step 1: Compute net correlation $c(u,v) = s(u,v) + \sum_{(i,j)\in E} s(u,i)\cdot s(j,v)$
Step 2: Compute affinity score $p(u,v) = c(u,v)\cdot r(u)$
Step 3: Connect the unconnected extrastriate node with the highest maximal affinity to its best-matching V1 source.
Step 4: Update E, k_u, $c(u,v)$, $r(u)$ until all extrastriate nodes are connected

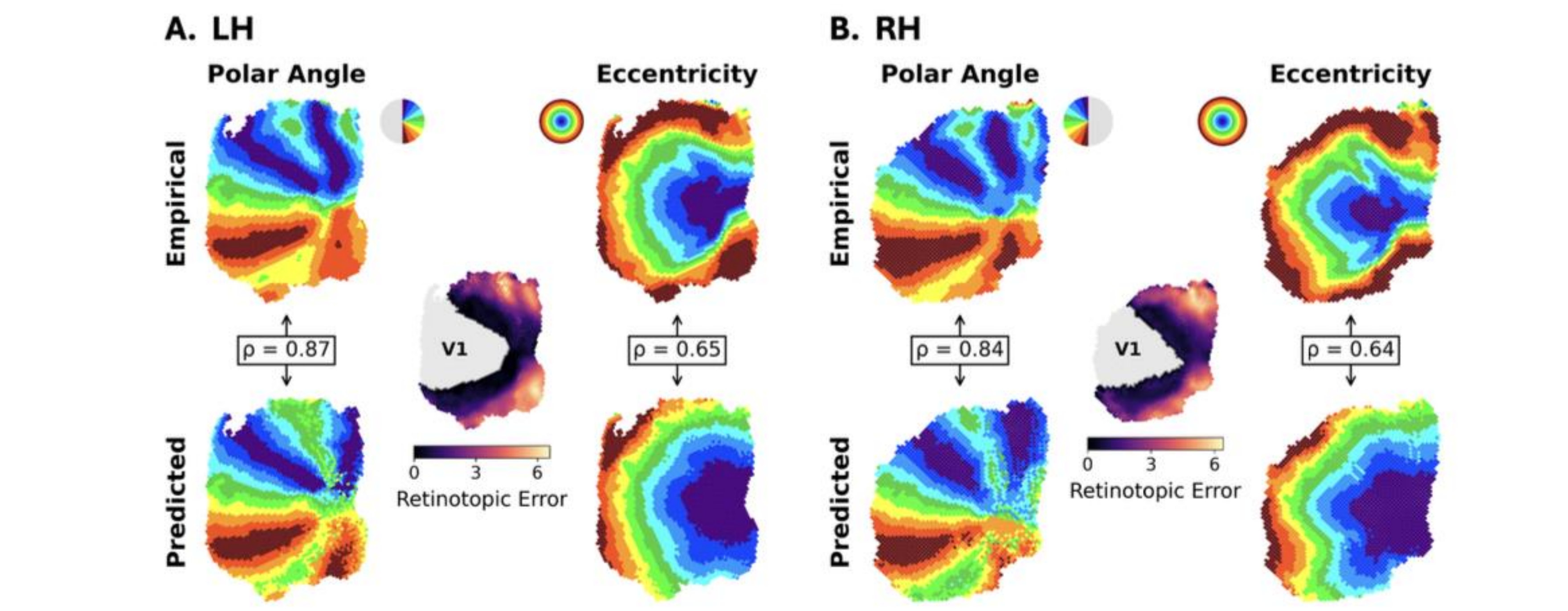
Result 1: Progressive formation of extrastriate maps

Parameters: (σ_R, σ_T)=(1.3, 2.2), fitted on the NMT
As growth propagates outward from V1, smooth retinotopic gradients and mirror-reversing extrastriate maps emerge progressively.

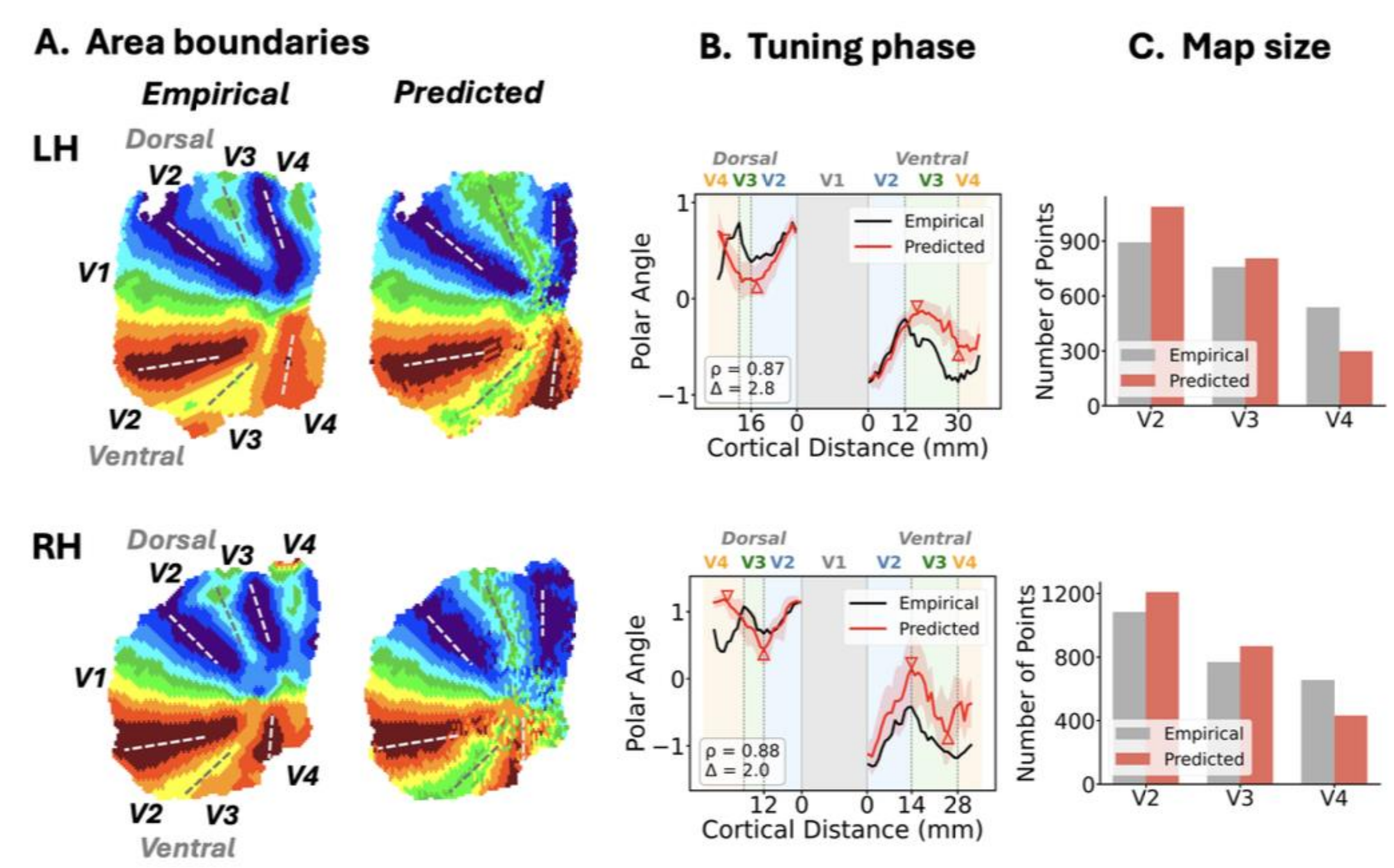


Result 2: Generated Maps Correspond to Empirical Retinotopy

The model reproduces both hallmark features of extrastriate retinotopy: mirror-reversing polar-angle maps and smooth eccentricity gradients.
NMT correspondence is high for polar angle **(ρ=0.87 LH, 0.84 RH)** and moderate-to-strong for **eccentricity (ρ=0.65 LH, 0.64 RH)**.



Result 3: Growth Model Produce Stereotypical Map Features



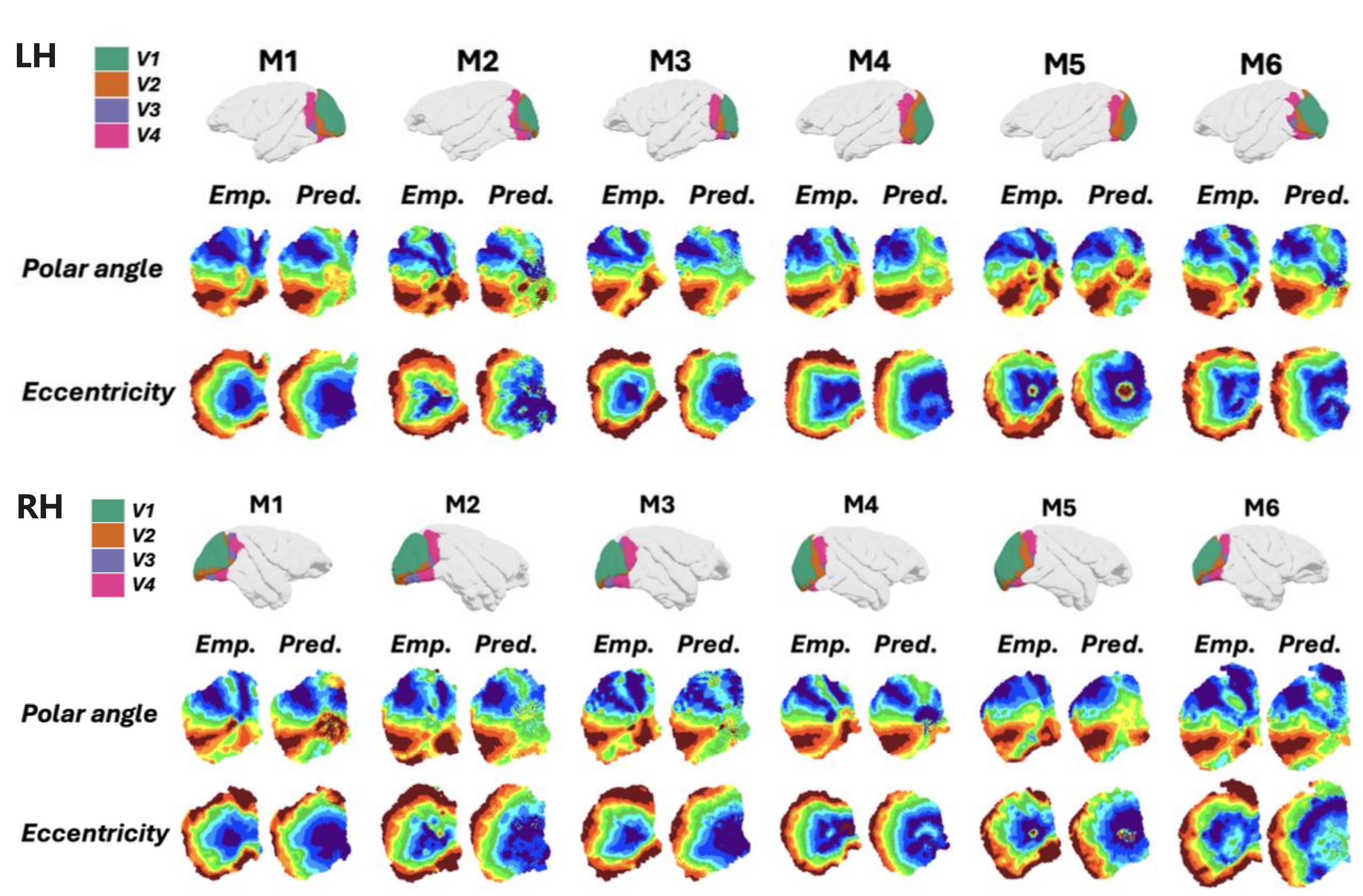
All boundaries closely match the empirical maps except the **dorsal V3-V4 boundary,** which is shifted anteriorly by approximately **5 mm**.

Average shift
LH: Δ=2.8mm
RH: Δ=2.0mm

Result 4: Growth Model Generalizes and Captures Individual Maps

The same fitted **growth rule and parameters** generalize across six macaques, indicating that the model is not only tuned to the population template.

Across individuals, empirical–predicted correspondence remains strong **(polar angle: ρ=0.74±0.03; eccentricity: ρ=0.60±0.10)**, showing that individual cortical geometry shapes fine-scale retinotopic variation around a shared scaffold.



Summary

- **Developmental dynamics:** Retinotopic structure emerges through sequential growth from V1, rather than predefined layout specification.
- **Map correspondence:** The model recovers both polar-angle reversals and eccentricity gradients on the population template.
- **Areal organization:** Boundary analysis tests whether mirror-reversal points align with V2–V4 transitions.
- **Individual variation:** The same rule set generalizes across monkeys, linking cortical folding to fine-scale retinotopic differences.

Future Work

- Incorporate additional anchors, such as **MT**[2], to possibly improve correspondence for more anterior extrastriate organization.
- Apply the framework to **humans** and calculate distances on fetal brains.

References

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