



RBF Quadrature for Neural Fields

Sage B. Shaw¹, Zachary P. Kilpatrick¹, and Daniele Avitabile²

1: University of Colorado Boulder 2: Vrije Universiteit Amsterdam



Summary

Goal: To create and test a neural field solver using radial basis function quadrature. The method should be

- High-order accurate
- Stable
- Geometrically flexible
- Fast (low complexity)

In the future, we will extend this to realistic curved 2D spatial domains.

Neural Field Models (NF)

- Tissue level models
- Integro-differential equation(s)
- Integral kernel represents neural network connectivity
- Non-linear firing rate function captures non-linear neural dynamics

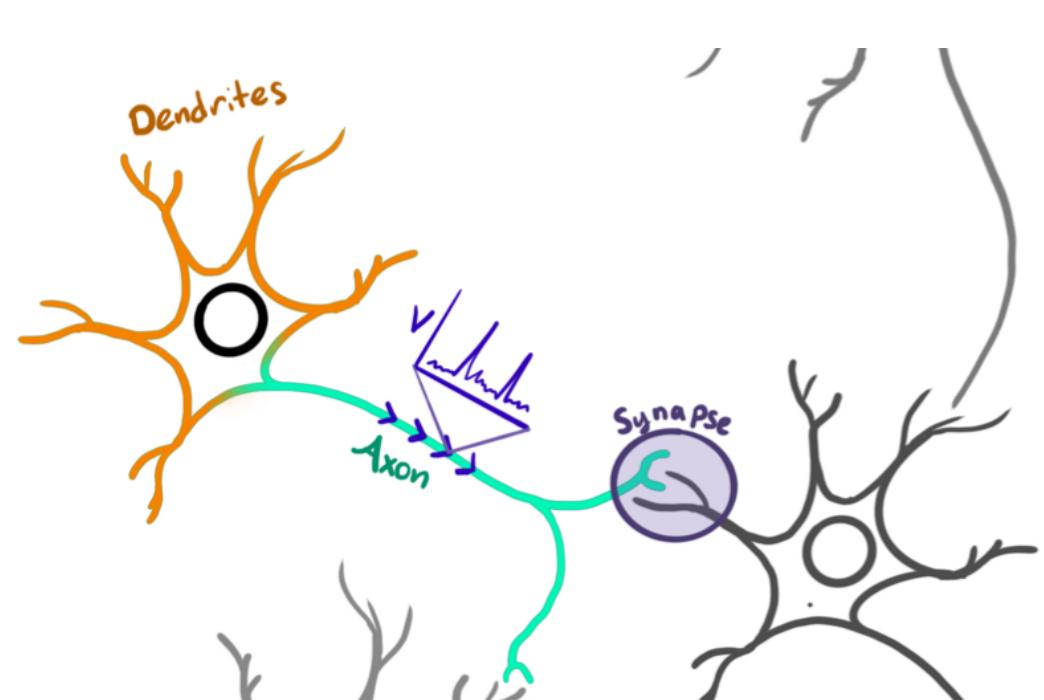
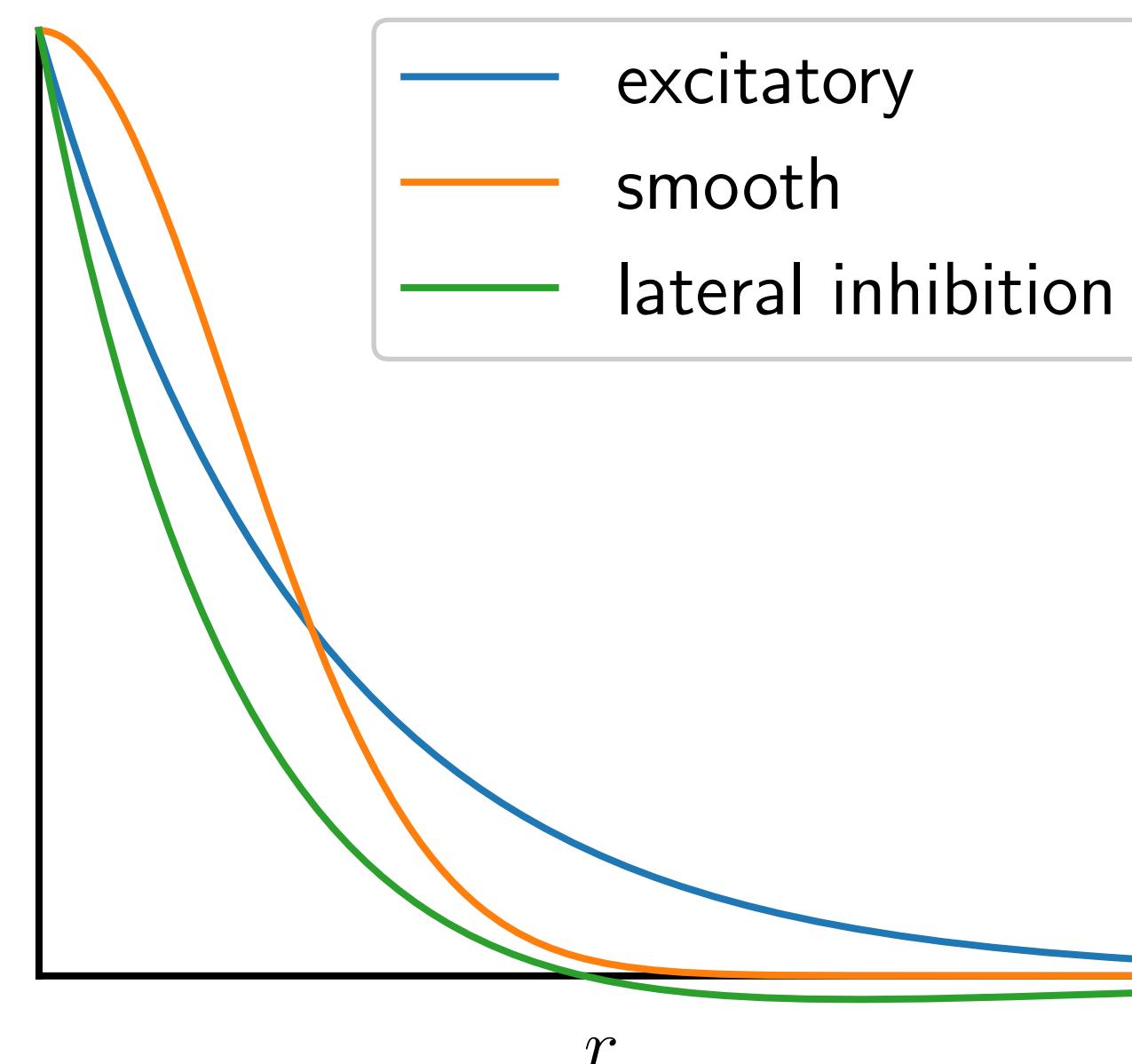


Image by Dr. Heather Cihak.

$$\partial_t u(t, \mathbf{x}) = -u + \iint_{\Omega} w(\mathbf{x}, \mathbf{y}) f[u(t, \mathbf{y})] d\mathbf{y}$$

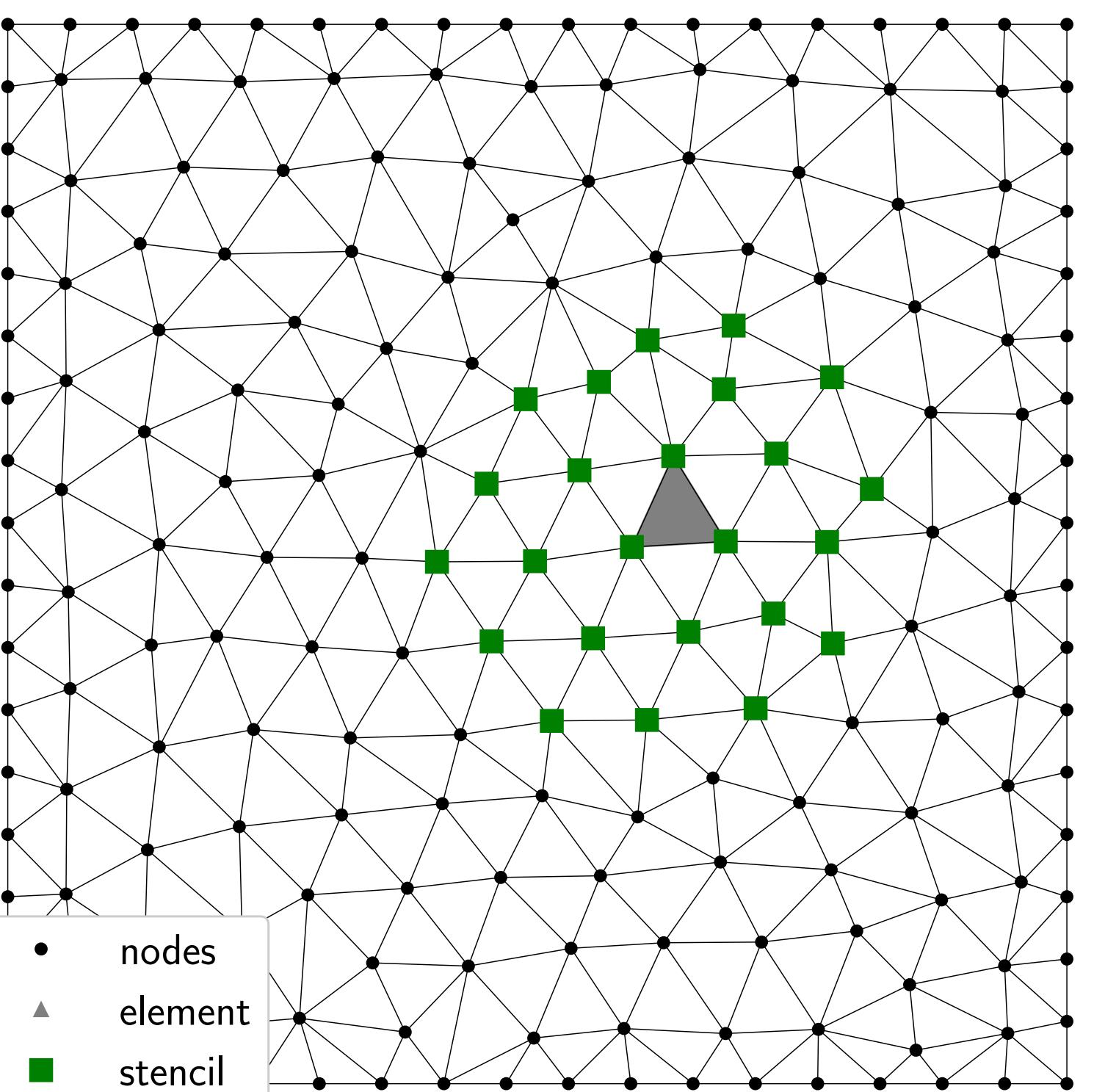
- $u(t, \mathbf{x})$ — Neural activity
- $w(\mathbf{x}, \mathbf{y})$ — Connectivity kernel
- $f(\cdot)$ — Non-linear firing rate function
- $\Omega = [0, 1]^2$ for now.

$$w(x, y) = w(\|x - y\|) = w(r)$$



Radial Basis Function Quadrature Formuale

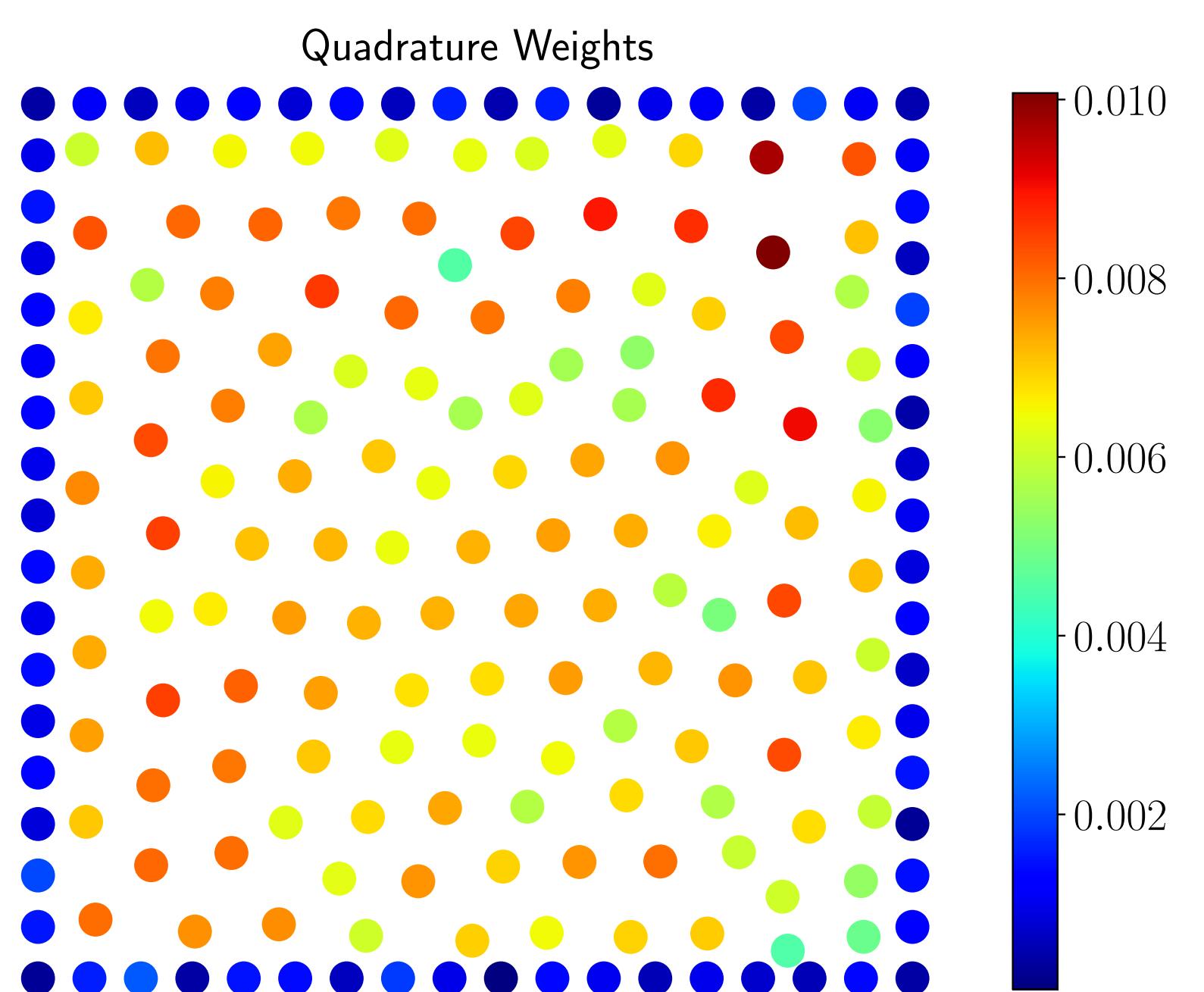
- Abbreviated **RBF-QF**
- Place N nodes in Ω
- Partition Ω into elements
- For each element
 - Select the k nearest nodes (the stencil),
 - Interpolate Lagrange functions,
 - Integrate over the element,
 - Sum over interpolants
- Sum over elements



The local interpolants have the form

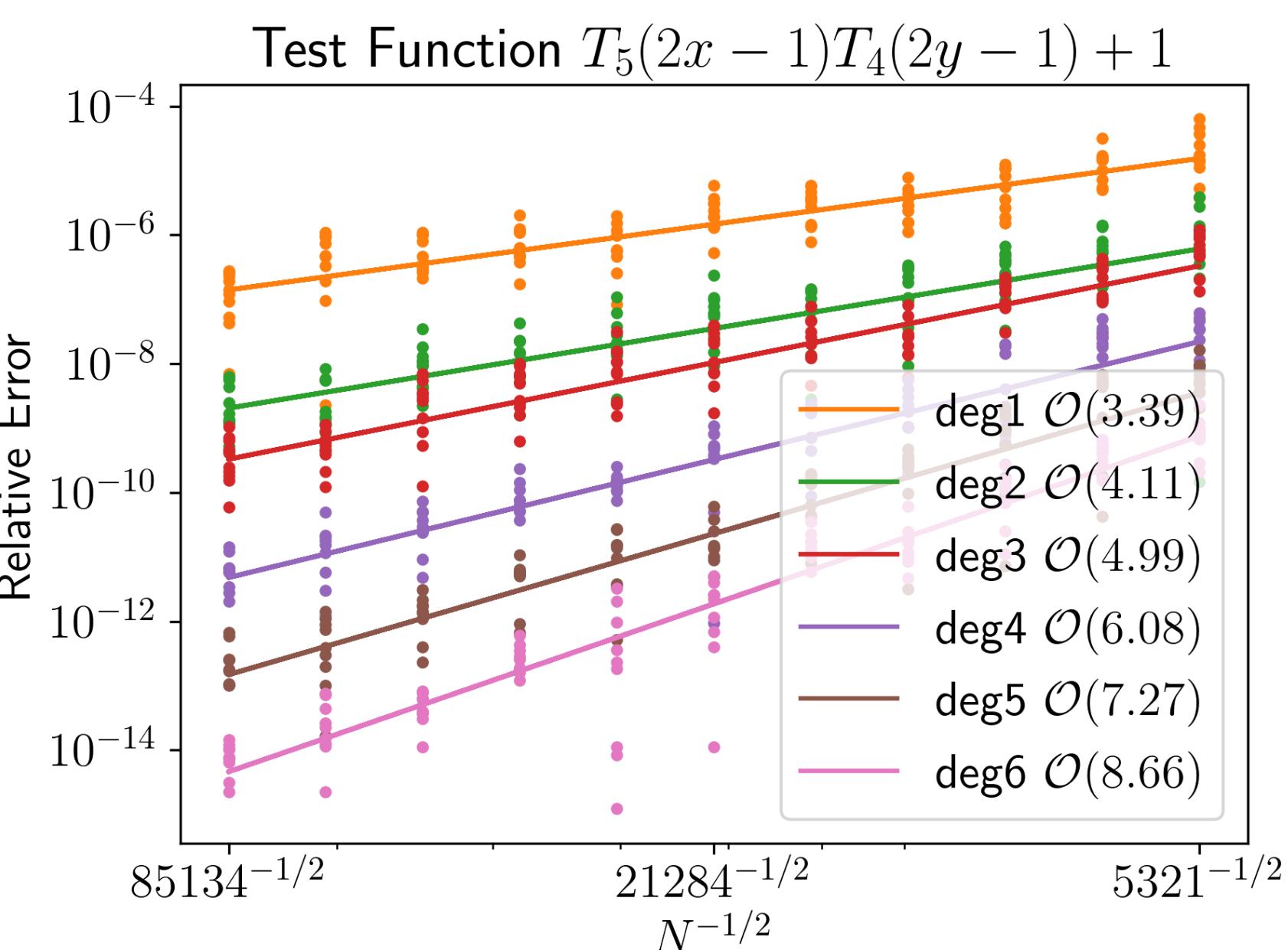
$$s(\mathbf{x}) = \sum_{i=1}^k c_i \phi(\|\mathbf{x} - \mathbf{x}_i\|) + \sum_{j=1}^m \gamma_j \pi_j(\mathbf{x})$$

- ϕ - radial basis function (eg. $\phi(r) = r^3$)
- $\{\pi_j\}_{j=1}^m$ - polynomial basis
- k interpolation conditions
- m moment conditions



Quadrature Convergence

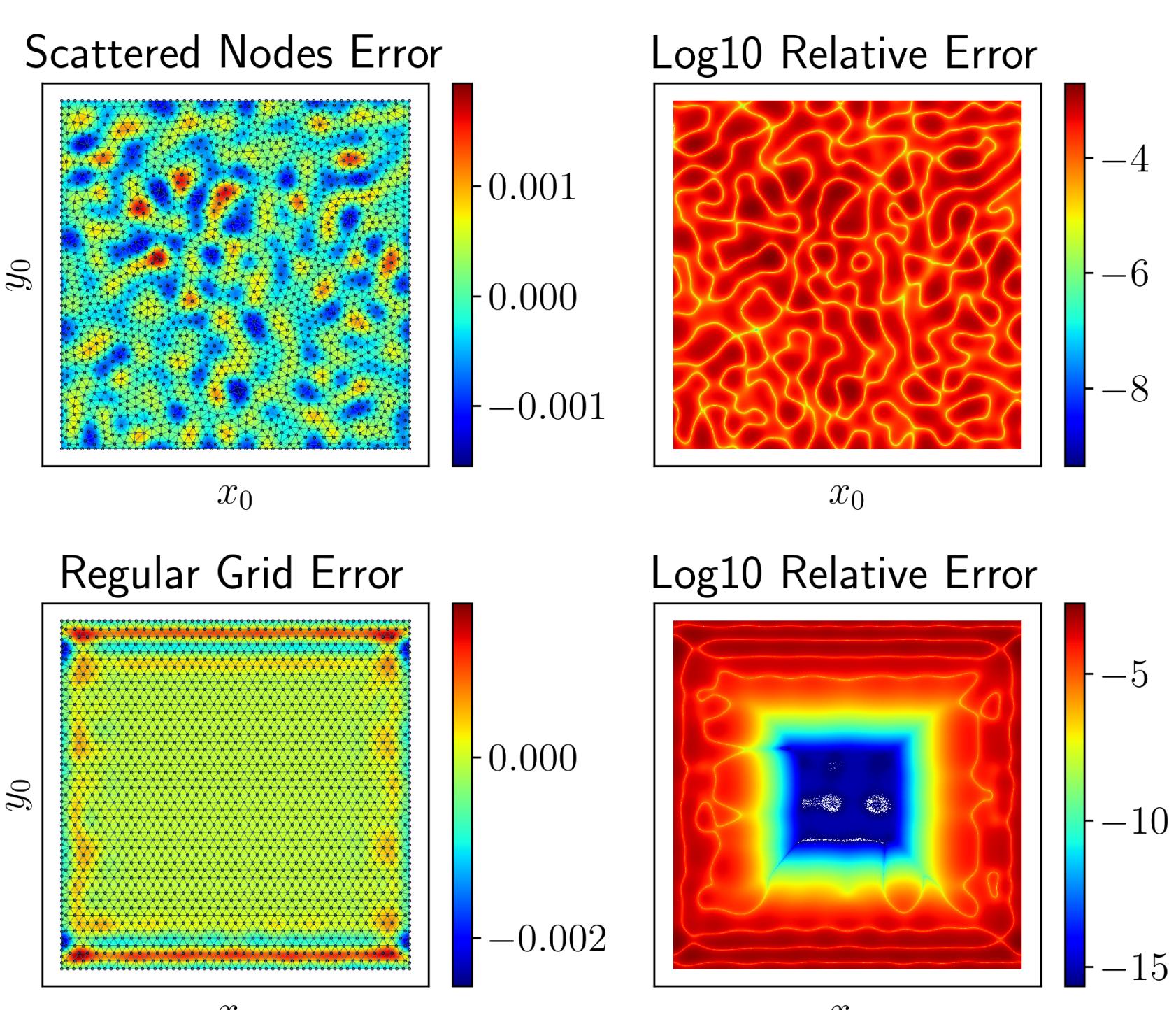
- No proven convergence rate.
- We expect at least $\mathcal{O}(d+1)$, where d is the degree of polynomial basis. (Think trapezoidal rule.)
- We test this on a product of Chebyshev polynomials.
- Area per point scaled like $\mathcal{O}(N^{-1/2})$



- Better convergence than expected

Spatial Analysis

- Gaussian test functions centered at (x_0, y_0)
- Scattered Nodes vs Regular Hex Grid



- Error is continuous w.r.t. (x_0, y_0)
- Hex grid has spectral accuracy away from boundary (like trapezoidal rule)

Next Steps

Projection Method[1]

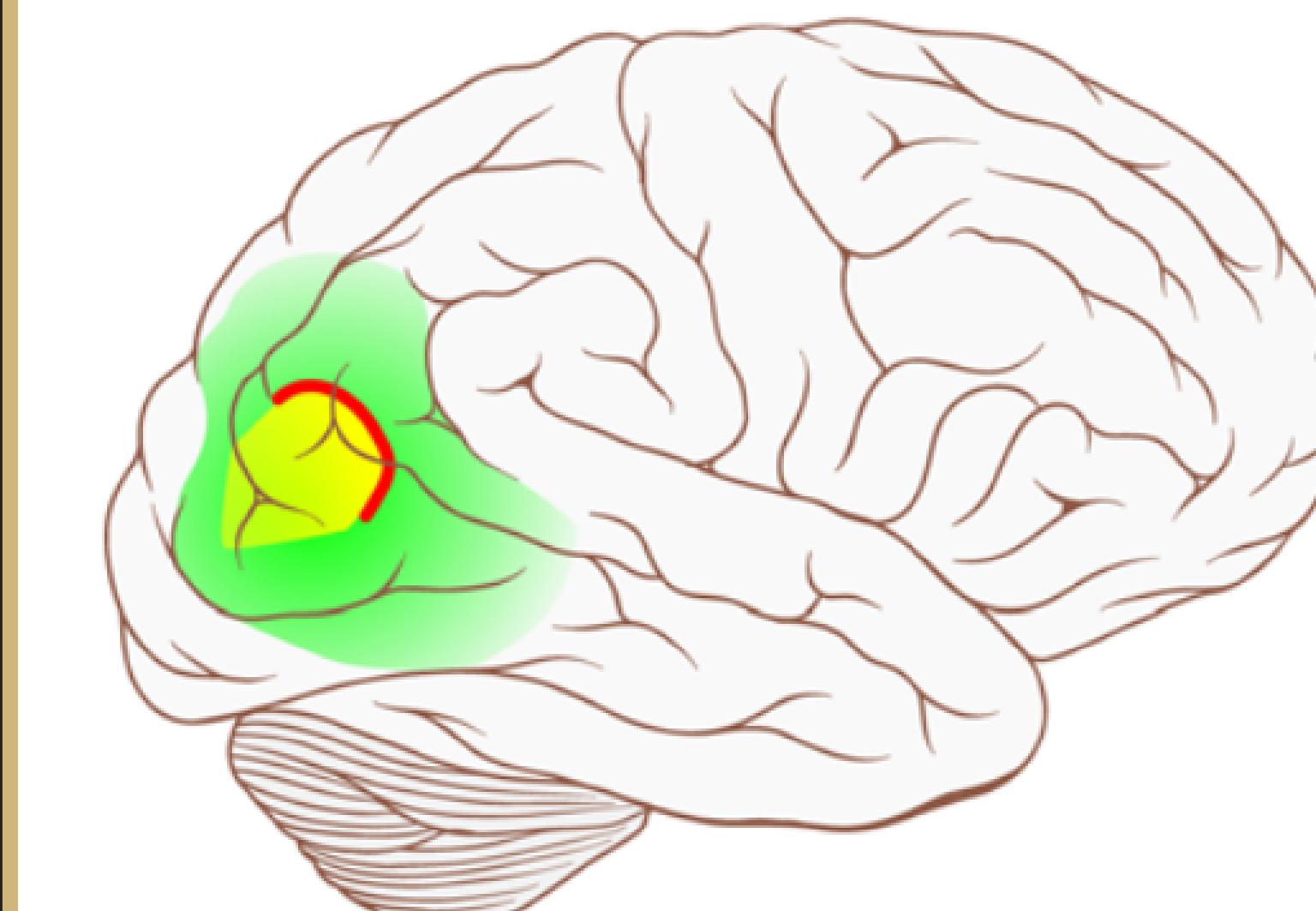
- Framework for error analysis of NF
- error = projection error + QF error
- We will unify these errors using RBF interpolation (projection) and RBF-QF.

Curved 2D Manifolds

- [2,3] Extended RBF-QF to 2D manifolds
- [4] Used FitzHugh-Nagumo (toy model) on torus (toy surface) to study effects of cortical curvature.
- We will use RBF-QF on realistic cortical surfaces to study the effects of cortical curvature on *cortical spreading depression* (CSD).

Cortical Spreading Depression

- Slow moving chemical wave
- Causes depressed neural activity
- Causes *scintillating scotomas*



Cartoon of CSD wave[5]



Artistic Rendering of Scotomas (see QR code)

References and Funding

1. D. Avitabile (2023) SIAM J. Numer. Anal.
2. Reeger et al. (2016) Proc. Royal A
3. Reeger & Fornberg (2018) J. Comp. Phys.
4. Kneer et al. (2014) New Journal of Physics.
5. M. Dahlam (2013) Chaos.

shawsa.github.io/presentations

This work is supported by

NSF DMS-2207700

NIH BRAIN 1R01EB029847-01