RBF Quadrature for Neural Fields

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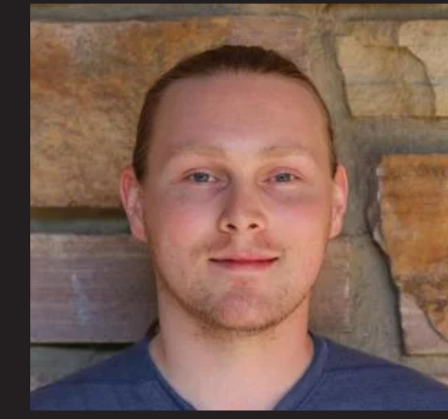


Summary

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

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

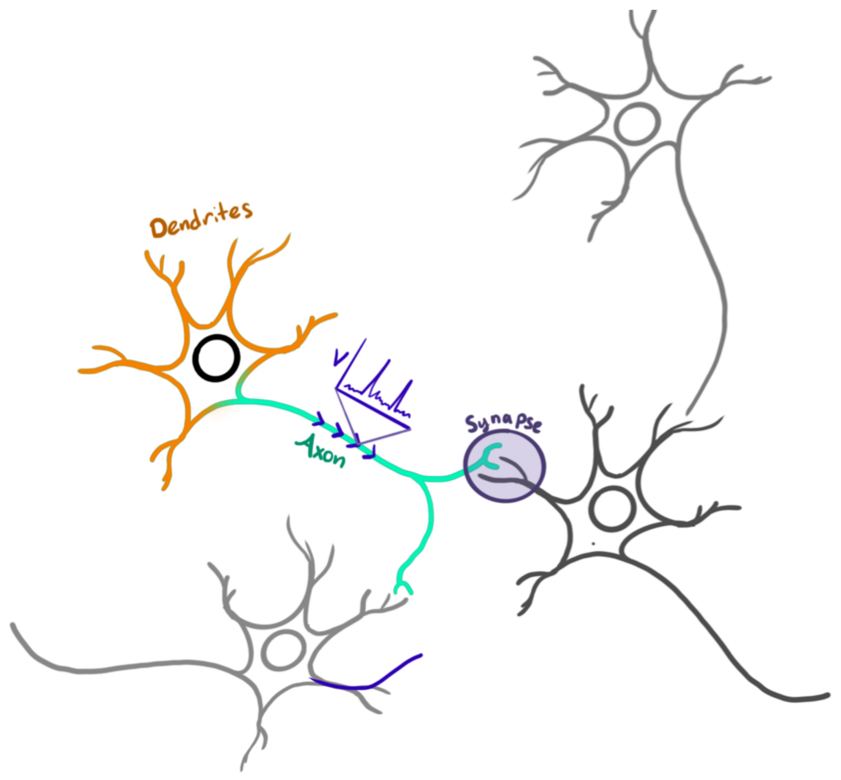


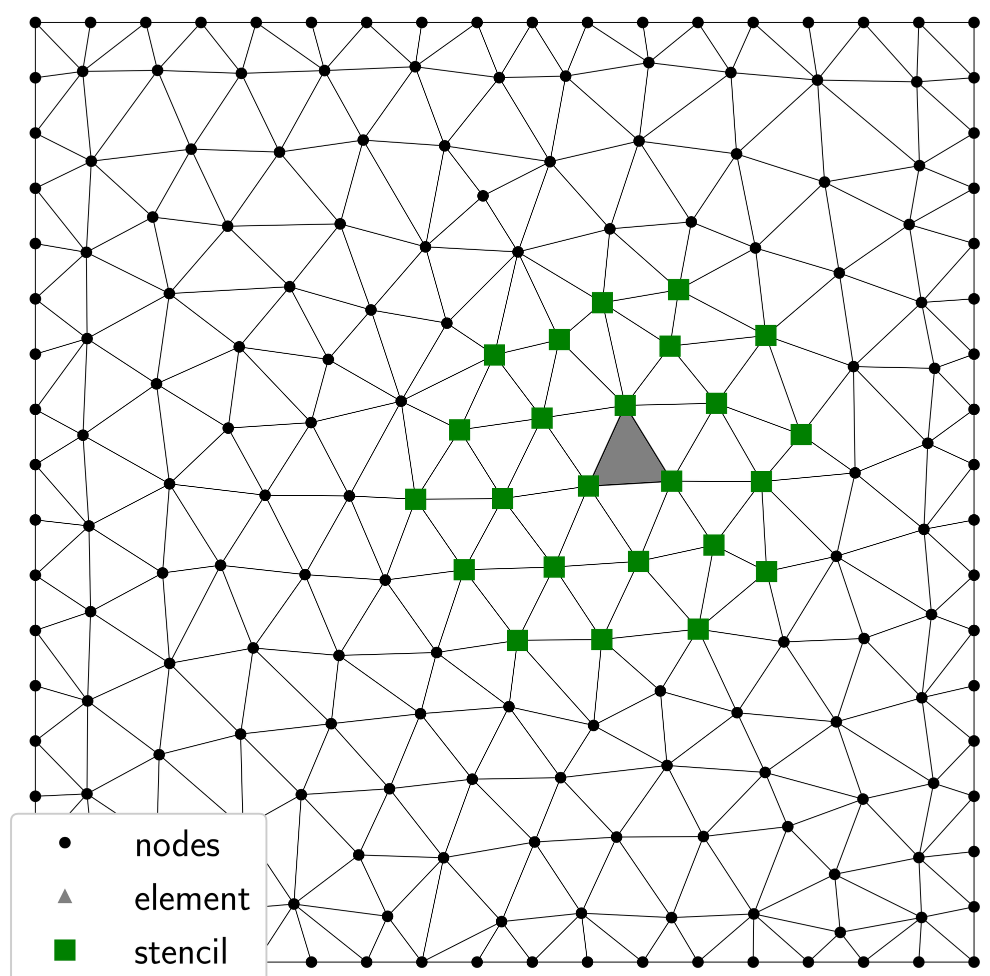
Image by Heather Cihak.

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

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

Radial Basis Function Quadrature Formuale

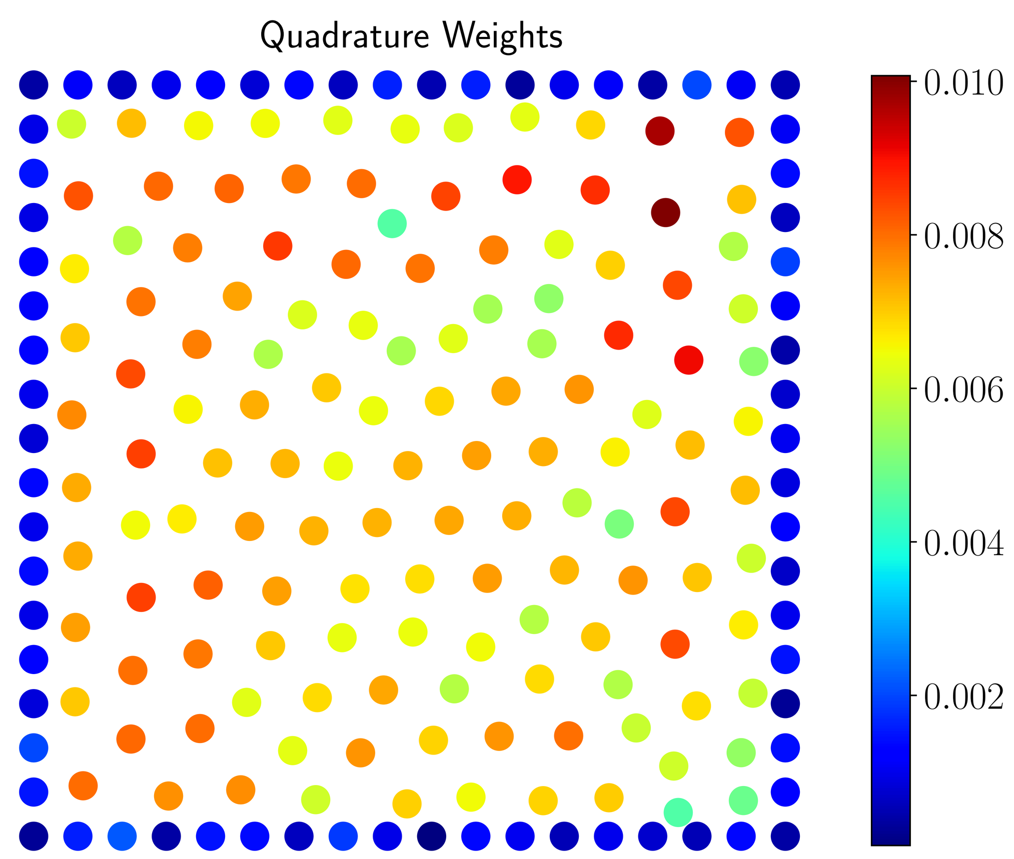
- Place N nodes in Ω
- Partition Ω into elements
- For each element
  - select the k nearest nodes (the stencil),
  - interpolate Lagrange functions,
  - integrate over the element,
  - sum over interpolants
- sum over elements



The local interpolants have the form

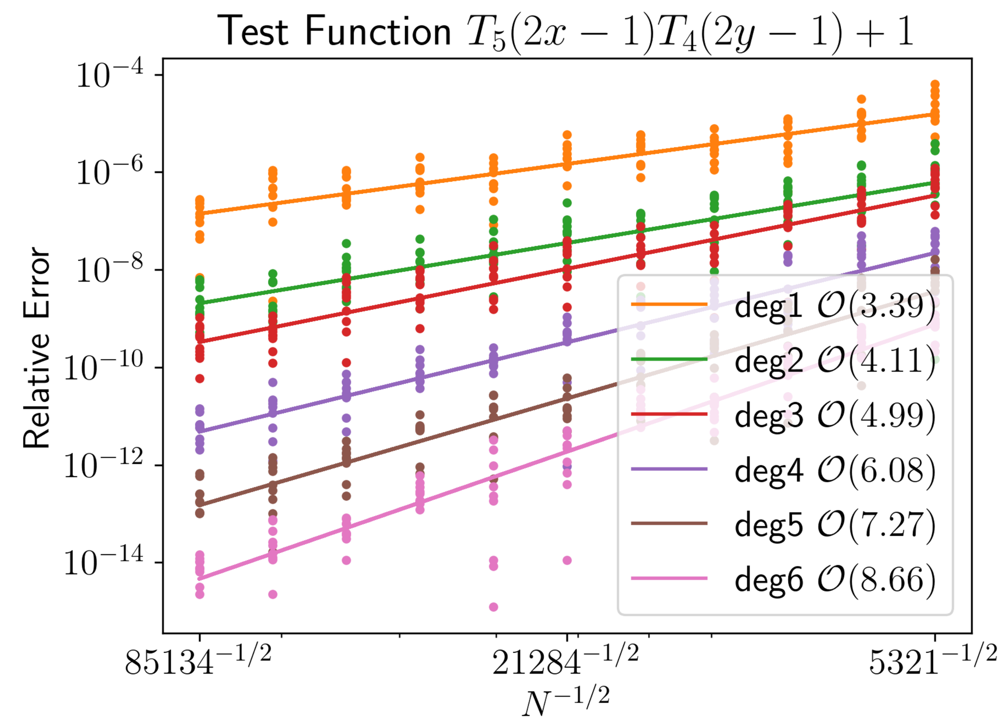
$$s(\mathbf{x}) = \sum_{i=1}^{k} c_i \phi(\|\mathbf{x} - \mathbf{x}_i\|) + \sum_{j=1}^{m} \gamma_i \pi_j(\mathbf{x})$$

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



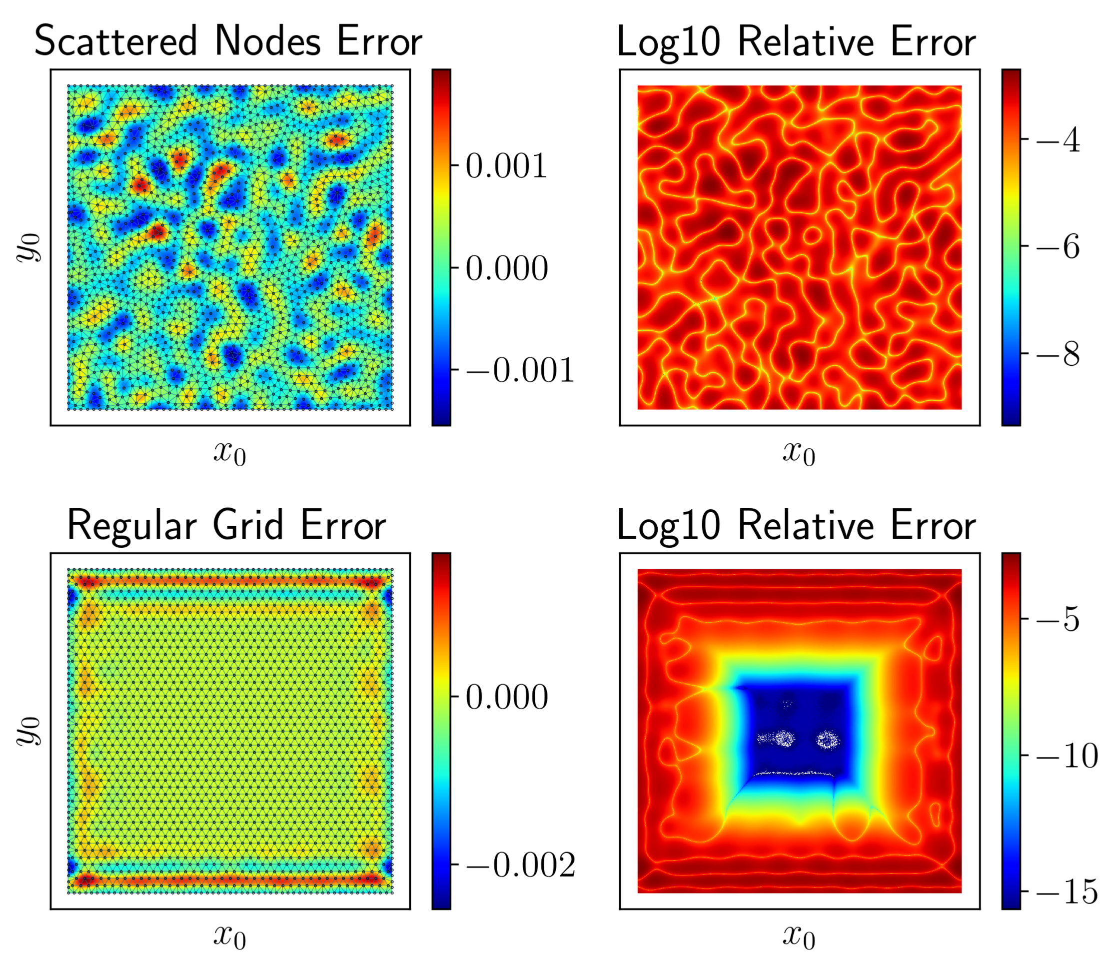
Quadrature Convergence

- 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.



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



Next Steps

Projection Method

- D. Avitable (2023)
- Framework for error analysis of neural field models
- Separates error into projection error and quadrature error
- We will unify these errors using RBF interpolation (projection) and RBF-QF.

Curved 2D Manifolds

- Reeger et al. (2016 & 2018)
- Extended RBF-QF to 2D manifolds
- We will

Corticol Spreading Depression

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- Extended RBF-QF to 2D manifolds
- We will

References and Funding

- Avitable (2023) SIAM J. Numer. Anal.
- Regeer et al. (2016) Proc. Royal A
- Reeger & Fornberg (2018) J. Comp. Phys.

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