Transport at Cornell

David Bindel

22 Mar 2025

Department of Computer Science
Cornell University

Three vignettes

- Heat transport: Walk on Spheres
- Alpha transport: A GPU-accelerated code
- Neutron transport: Differentiable rendering

All thanks to Michael Czekanski

Vignette 1: Walk on Spheres

Basic idea: $\nabla^2 u = 0$ implies

$$u(x) = E_{Z \sim U(S^1)}[u(x + \rho Z)]$$

if a ball of radius ρ about x fits in Ω.
So:

- Pick sphere of radius $d(x, \partial\Omega)$
- Pick a random point on the sphere
- Repeat until close enough to $\partial\Omega$

Plays well with GPUs.

Walk on Spheres

"Walking on Spheres and Talking to Neighbors: Variance Reduction for Laplace's Equation" (arXiv:2404.17692). Czekanski, Faber, Fairborn, Wright, Bindel.

Idea: Share information if solution wanted at many points.

- Better than basic WoS for solutions at many points
- Doesn't require meshing
- Unclear that it beats other mesh-free methods
- And doesn't work great with anisotropy

Next steps?

- Combining WoS with variational methods
  - Expand temperature in bases on nested (approx) flux surfaces
  - Walks to estimate transfer operator between surfaces
  - Solve coupled problem with standard linear solver
- Geometry-adapted radial basis function approach

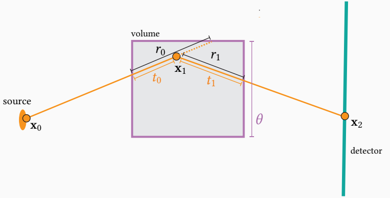
Vignette 2: Neutrons, graphics style!

Co-conspirators:

- Steve Marschner (Cornell CS)
- Xi Deng (Cornell CS) - *looking for postdocs!*
- Maoseng Tang (Cornell CAM)
- Michael Czekanski (Statistics)

+ conversations with Patrick Shriwise, Paul Romano, Paul Wilson.

Differentiable rendering idea



- Simulate photon/neutron transport via MC
- Reparameterize to enable differentiation wrt geometry

Demo

https://www.cs.cornell.edu/~xideng/int.html

Next steps

Are many!

- Multiple energies.
- More complex scattering behavior.
- Work with Wenzel Jacobs on extra Mitsuba support.
- Looking for funding on this.

Monte Carlo Methods for Stellarator Design

Michael Czekanski

Cornell University

Monte Carlo Methods

- Charged particle tracing
- Mesh-free heat transport methods
- Neutron transport

GPU particle tracing

- Guiding center equations
- Vacuum field
- Boozer coordinates

Results (compared to simsopt)

- Max abs. error in interpolation: $<$1e-11
- Max abs. error in single time step: $<$ 1e-19 in dt, 1e-12 in pos., 1e-7 in v_parallel

Speed up

- 25,000 particles for 0.01s
- Tracing takes ~82s of wall clock time

Loss comparison