Radiation Transport in Stochastic Media: Variance Deconvolution

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Introduction

Department and University: UC Berkeley Nuclear Engineering
Academic Advisor: Prof. Jasmina Vujic, Prof. Anil Prinja (UNM)
NSSC Research Focus Area(s): Modeling and Simulation
Academic Standing: 2nd Year PhD

Lab Mentor and Partner National Laboratory: Dr. Patrick Brantley (LLNL), Dr. Aaron Olson (SNL)

Mission Relevance of Research: Radiation transport in extreme environments


Dr. Patrick Brantley


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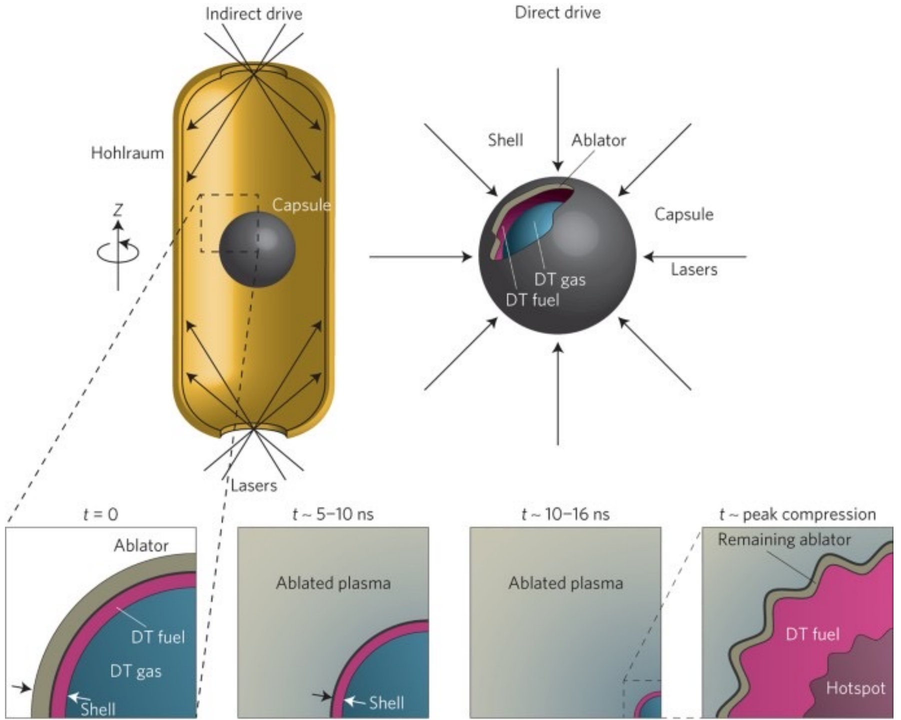
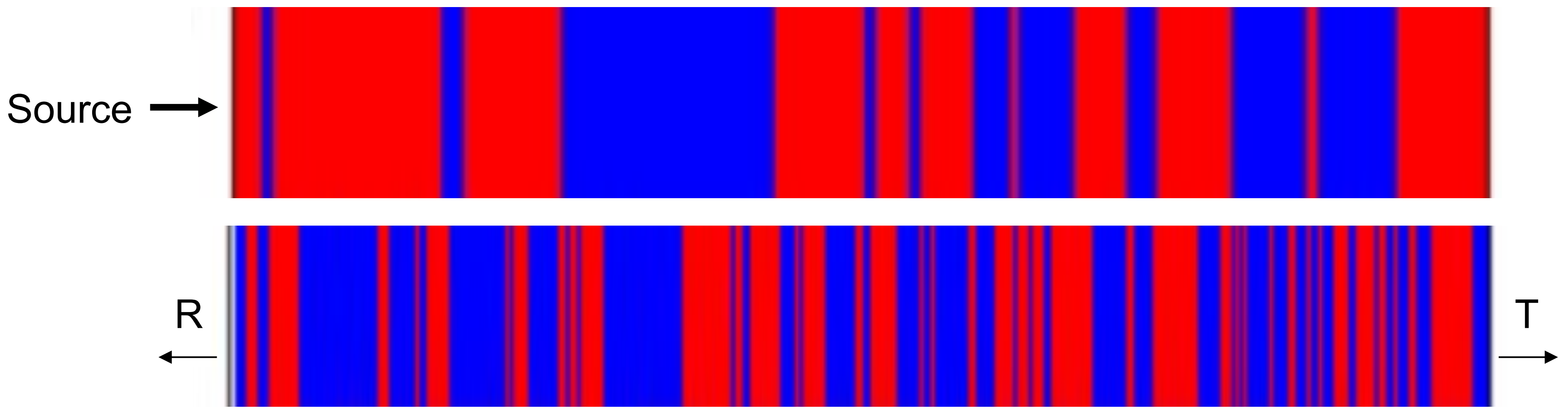
Radiation Transport in Stochastic Media

- Stochastically mixed media arise in diverse applications:
  - Inertial confinement fusion
  - Pebble-bed nuclear reactors
  - Nuclear astrophysics
- Radiation transport on stochastic geometries is extremely challenging
- Direct numerical simulations are computationally expensive
- It is necessary to develop approximate models that yield accurate means and variances



Radiation Transport in Stochastic Media

- Monte Carlo methods often used
- Average and **Variance** of transport outputs are of interest
- Generating representative geometries is slow, so we need faster numerical methods
- Monte Carlo methods have inherent noise/uncertainty that must be quantified
- 1D planar geometry used to study methods



Monte Carlo Stochastic Media Transport Methods

Chord Length Sampling (CLS)

- Treats material switching as an interaction
- No memory of geometry
- Faster, but less flexible
- Mixing statistics need to be known
- Each particle is completely independent

Conditional Point Sampling (CoPS)

- Evaluates material at a pseudo-collision point
- Flexible amounts of memory
- Slower, but more flexible
- Knowledge of mixing statistics not necessary
- Particles can share memory (cohort)

Variance Deconvolution

$$\mathbb{V}\mathrm{ar}[Q] = \mathbb{V}\mathrm{ar}_{\omega}\left[\tilde{Q}\right] - \frac{\mathbb{E}_{\omega}\left[\sigma^2\right]}{N_{\eta,\tilde{Q}}}$$

N_{η,σ^2}

$N_{\eta,\tilde{Q}}$

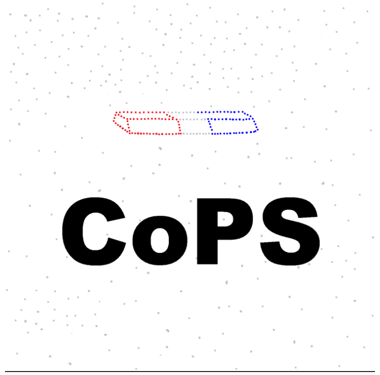
- Variance on quantity of interest Q
- Variance is polluted by noise, represented by $\tilde{Q}$
- Mean Monte Carlo noise σ^2 must be removed

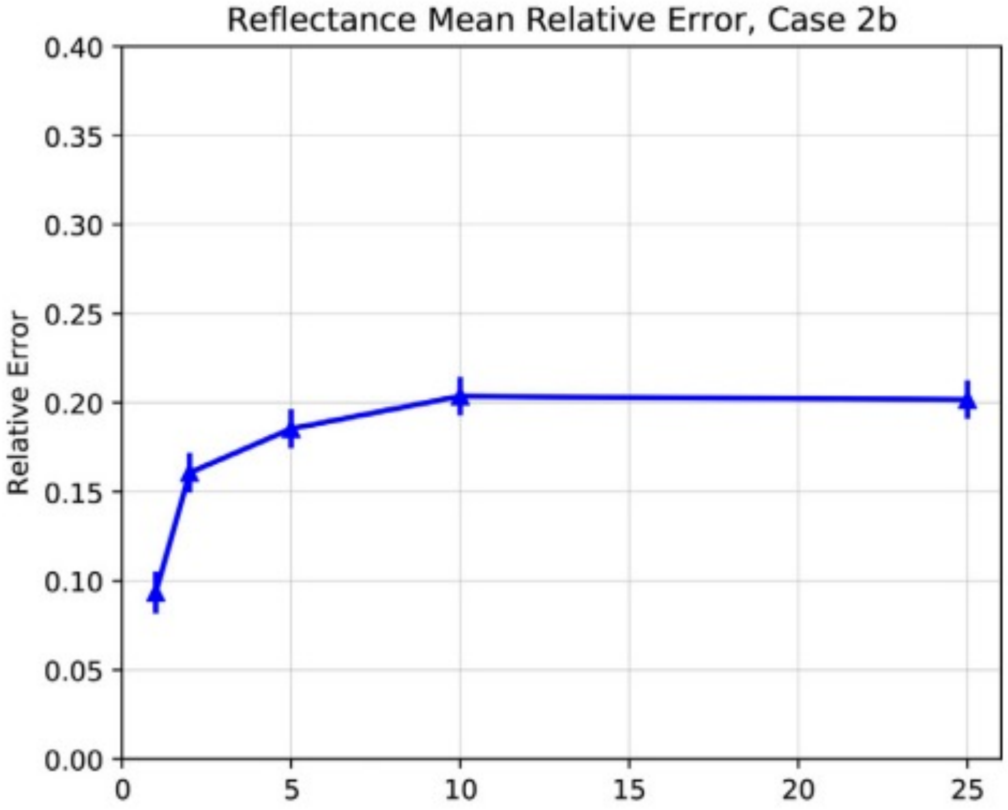
Error Propagation in CoPS

- CoPS *can* be errorless, but is generally not (and wouldn't be for any application)

- Shared memory can therefore propagate error

- Error propagation means samples are not independent and identically distributed (IID)



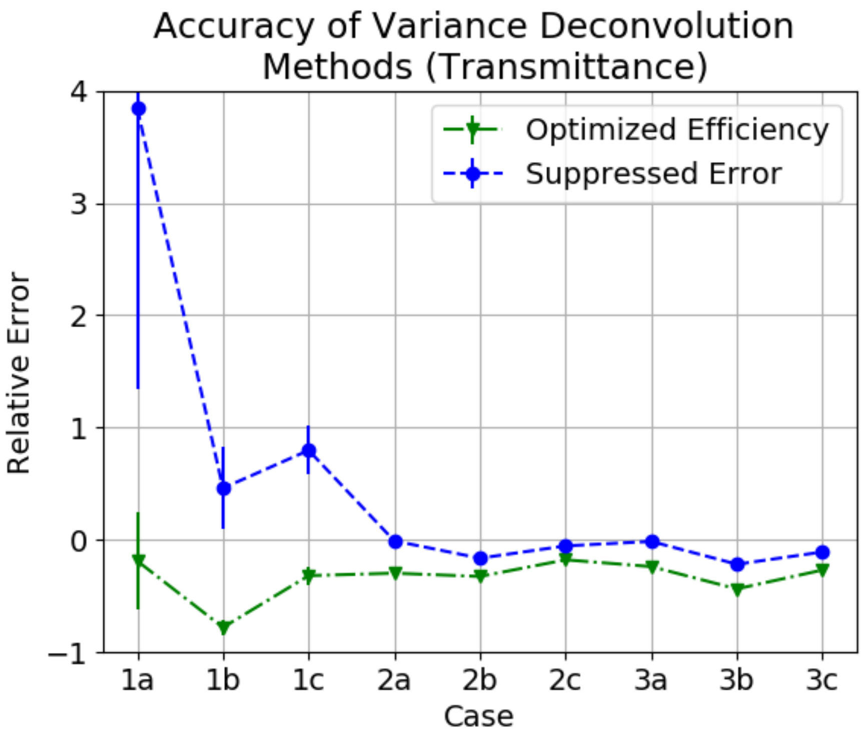


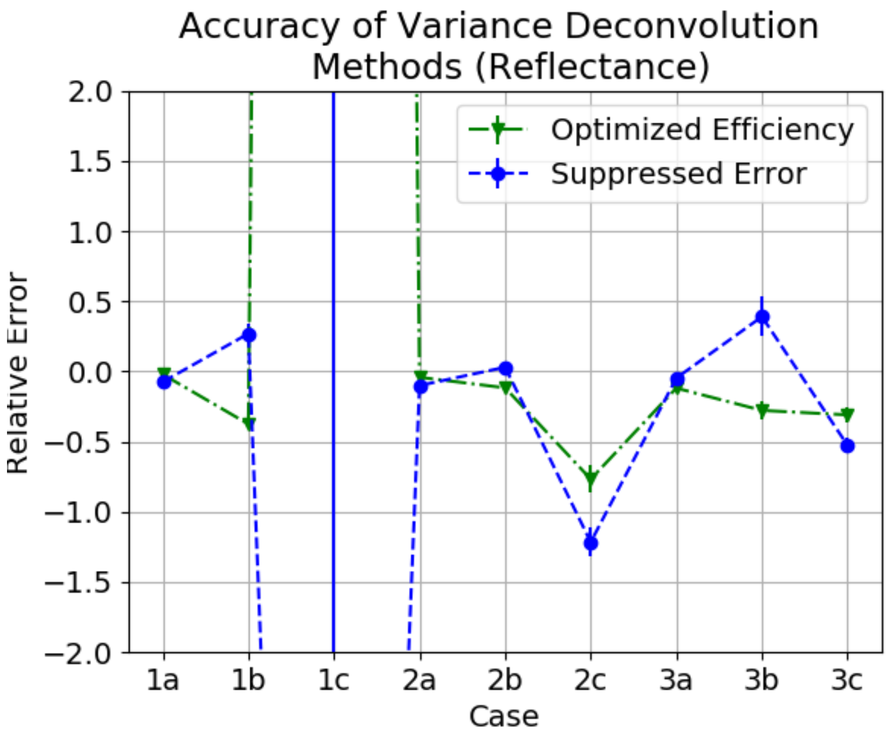
Variance Deconvolution with CoPS: Two Approaches

Optimized Efficiency (OE)	Suppressed Error (SE)
$N_{\eta,\tilde{Q}} = N_{\eta,\sigma^2}$	$N_{\eta,\tilde{Q}} = 1$
Minimize uncertainty (maximize efficiency)	Minimize error introduced from CoPS

1. Is the SE or OE approach more **accurate** when paired with CoPS, or is it problem dependent?
2. Is the OE approach still more **efficient** when paired with CoPS even though CoPS histories are not IID?

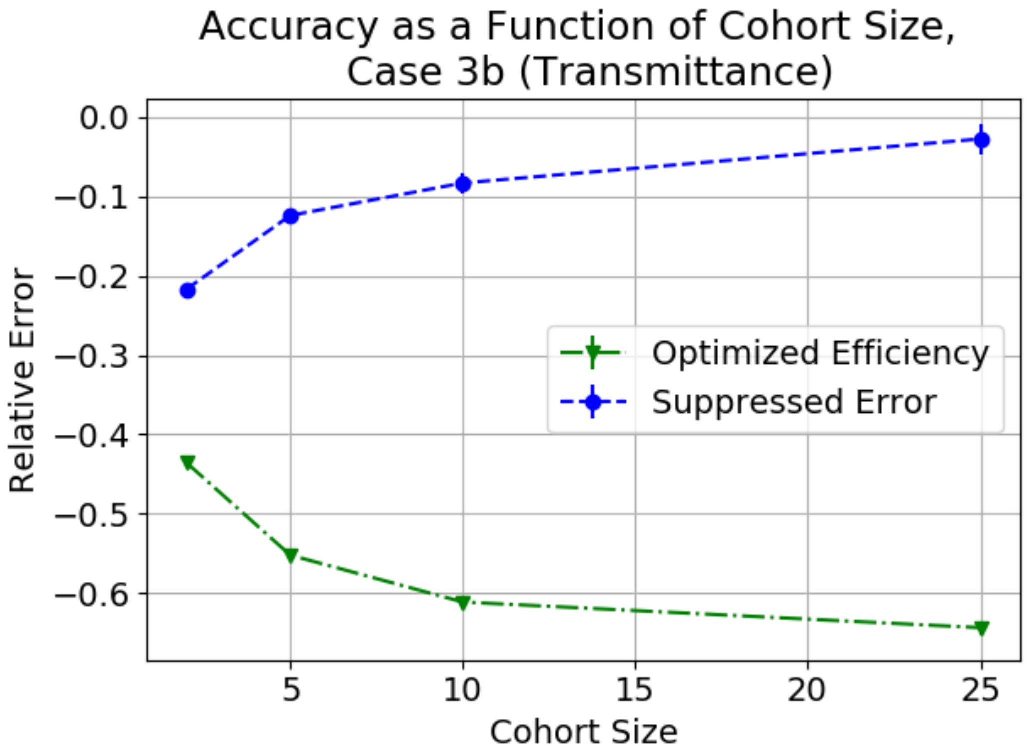
The Results: Accuracy

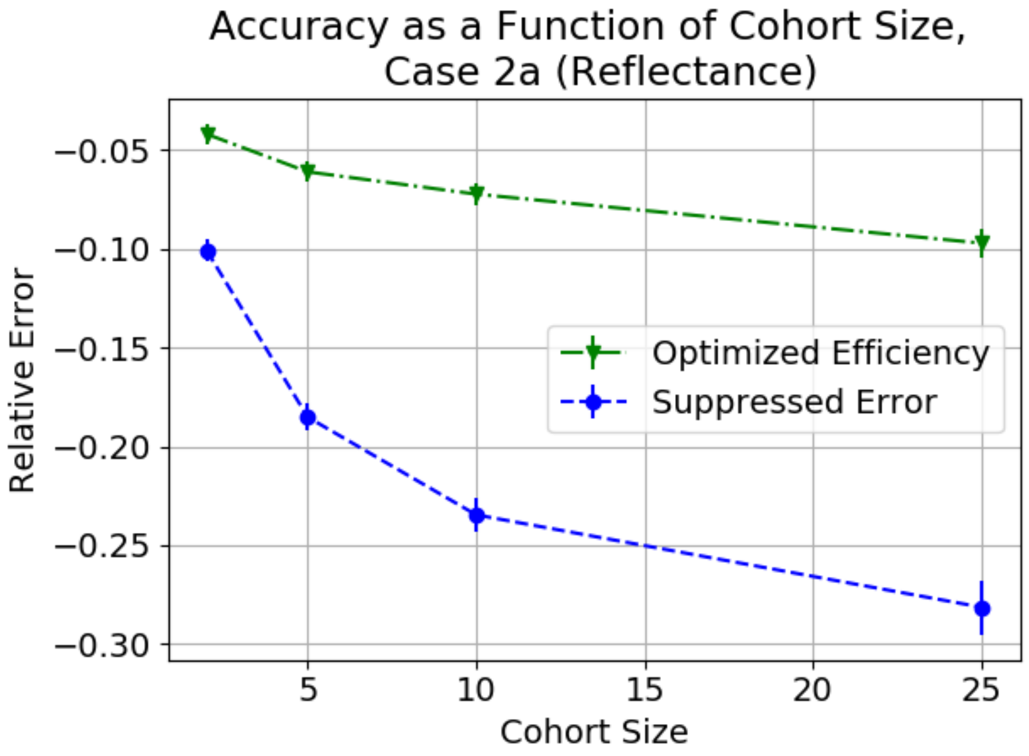




SE more accurate in 11/18 cases
OE may be better for cases with finer mixing (Case 1)

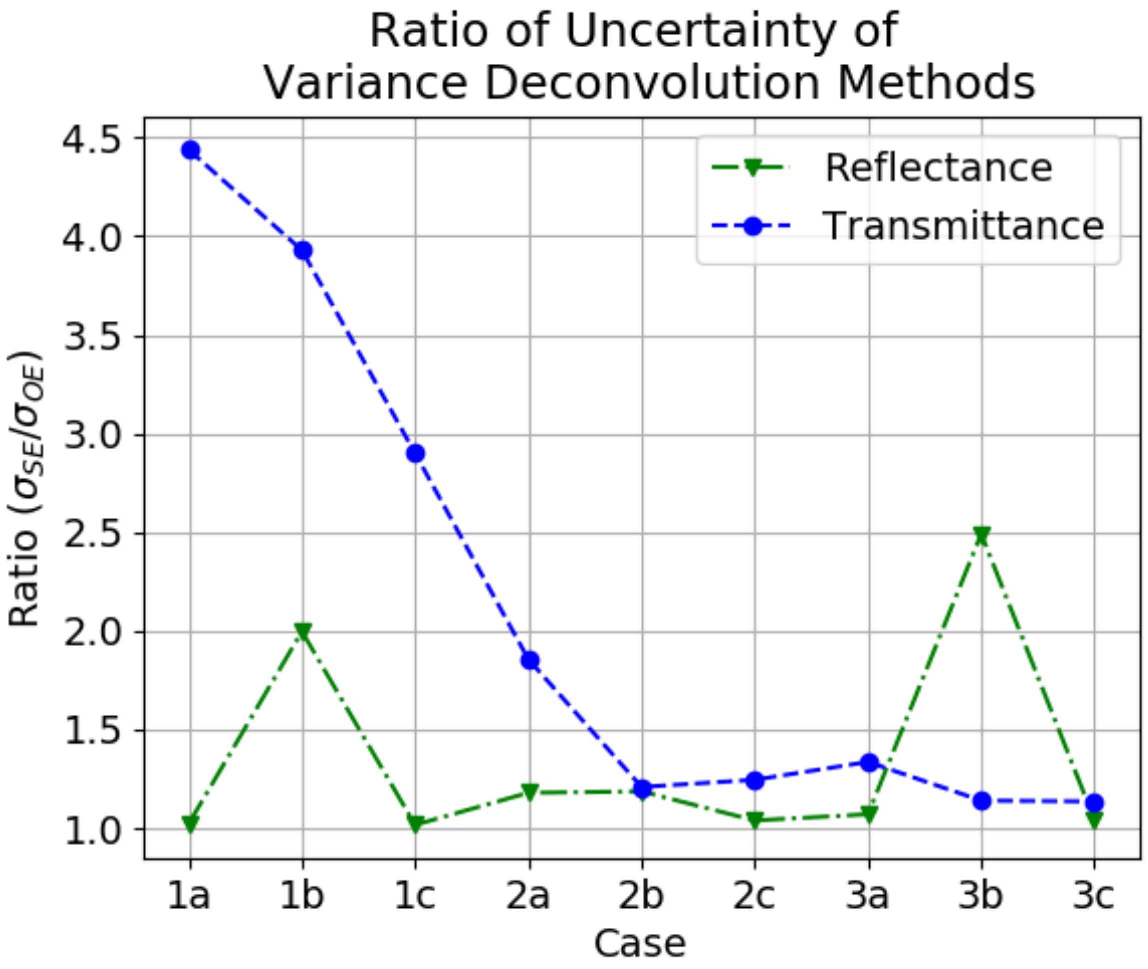
The Results: Accuracy (cont)





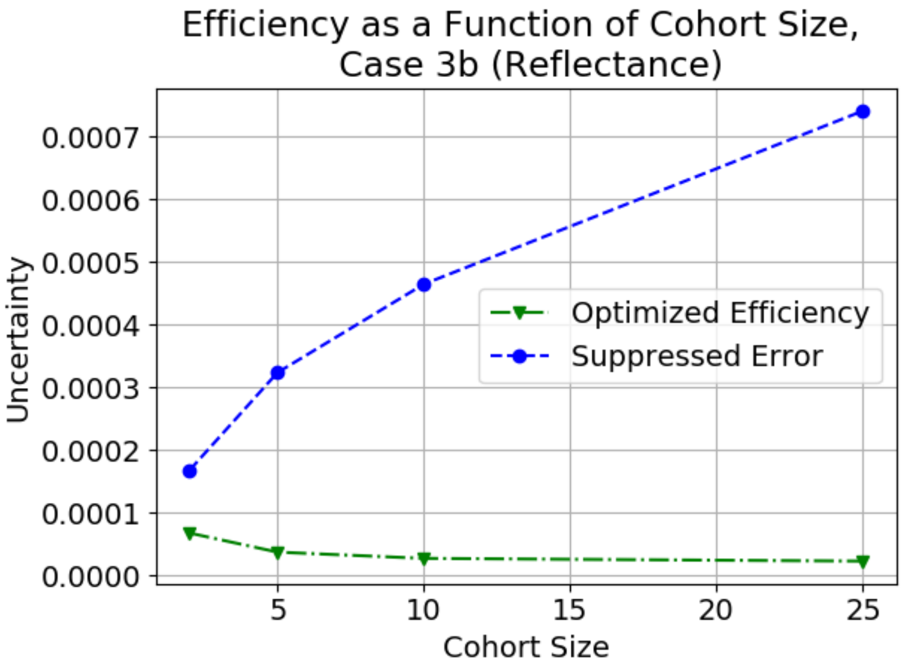
Accuracy behavior as a function of cohort size is largely unpredictable

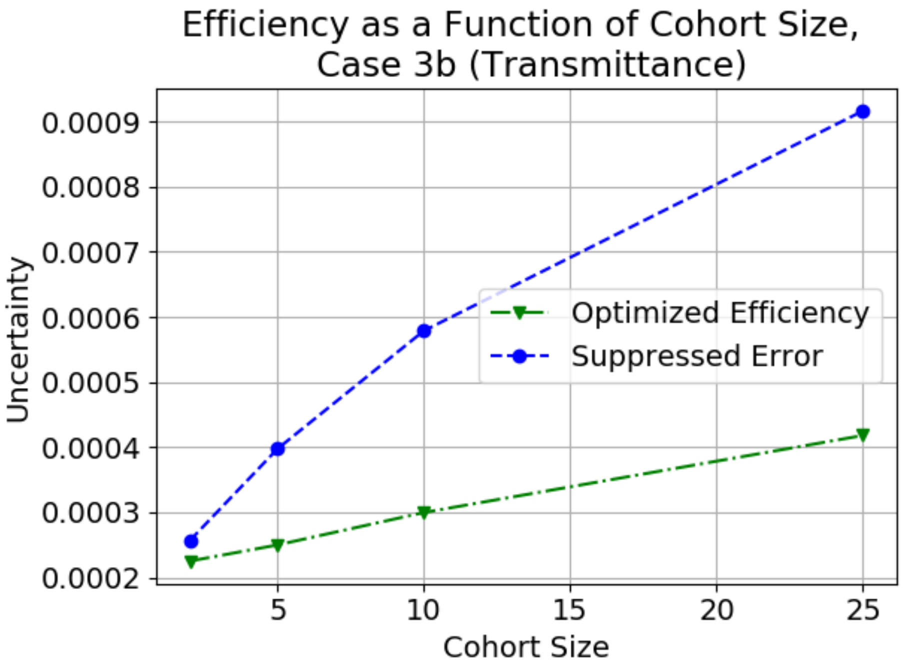
The Results: Efficiency



OE was more efficient for all tested cases

The Results: Efficiency (cont.)





Conclusions

- OE was more efficient for all tested cases
- SE was more accurate for 11/18 cases
- OE was more accurate for finer mixing, SE was more accurate for coarser mixing
- Accuracy behavior as a function of cohort size is largely unpredictable
- Behavior is very case dependent
- Future work can include:
    - More cases to test for trends with material properties
    - Optimal number of particles per cohort used to maximize efficiency while minimizing error
    - 3D to represent applications better
    - Theoretical work on variance deconvolution for non-IID radiation transport samples

The NSSC Experience

<u>Collaborations and Connections:</u>

- Intern at LANL in XTD-IDA (Summer 2022)
- Intern at SNL Org. 1341 (Summer 2023)
- Future collaboration with LLNL
- Co-advisor Prof. Anil K. Prinja is at UNM

<u>Conferences and Workshops:</u>

- UPR 2023 Poster Presentation
- NSSC Fall Workshop 2023
- Upcoming ANS Winter Meeting 2023

Acknowledgements

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