

# Krylov Linear Solvers and Quasi Monte Carlo Methods for Transport Simulations

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## **Abstract**

QMC + Krylov

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## I. INTRODUCTION

## II. COMPUTATIONAL RESULTS

In this section we consider an example from [1]. The formulation of the transport problem is taken from [2]. The equation for the angular flux  $\psi$  is

$$\mu \frac{\partial \psi}{\partial x}(x, \mu) + \Sigma_t(x) \psi(x, \mu) = \frac{1}{2} \left[ \Sigma_s(x) \int_{-1}^1 \psi(x, \mu') d\mu' + q(x) \right] \text{ for } 0 \leq x \leq \tau \quad (1)$$

The boundary conditions are

$$\psi(0, \mu) = \psi_l(\mu), \mu > 0; \psi(\tau, \mu) = \psi_r(\mu), \mu < 0.$$

### II.A. Source Iteration and Linear Solvers

Source iteration is Picard iteration for the fixed point problem

$$\phi = \mathcal{S}(\phi, q, \psi_l, \psi_r)$$

To use other solvers we must convert to a linear system via

$$\mathcal{K}(\phi) = \mathcal{S}(\phi, 0, 0, 0) \text{ and } f = \mathcal{S}(0, q, \psi_l, \psi_r)$$

to get

$$A\phi \equiv (I - \mathcal{K})\phi = f,$$

which we can send to a linear solver.

In the computaions we use the problem from [1]

$$\tau = 5, \Sigma_s(x) = \omega_0 e^{-x/s}, \Sigma_t(x) = 1, q(x) = 0, \psi_l(\mu) = 1, \psi_r(\mu) = 0,$$

and consider two cases  $s = 1$  and  $s = \infty$

## II.B. QMC and Krylov Linear Solvers

The linear and nonlinear solvers come from the Julia package [SIAMFANLEQ.jl](#) [3]. The documentation for these codes is in the [Juila notebooks](#) [4] and the book [5] that accompany the package.

We solve the QMC linear problem with  $N=1000$  and  $N_x=100$ . We use two krylov methods [6], GMRES [7] and Bi-CGSTAB [8]. Figures 1 and 2 show that the Krylov iterations take fewer than half of the number of transport sweeps that Picard iteration required.

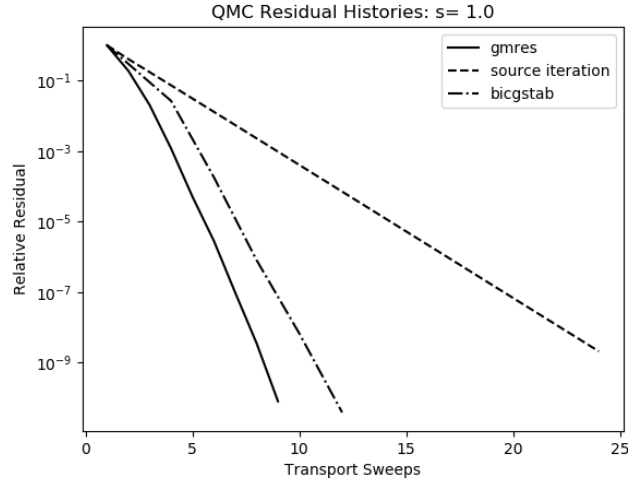


Fig. 1.  $s = 1$

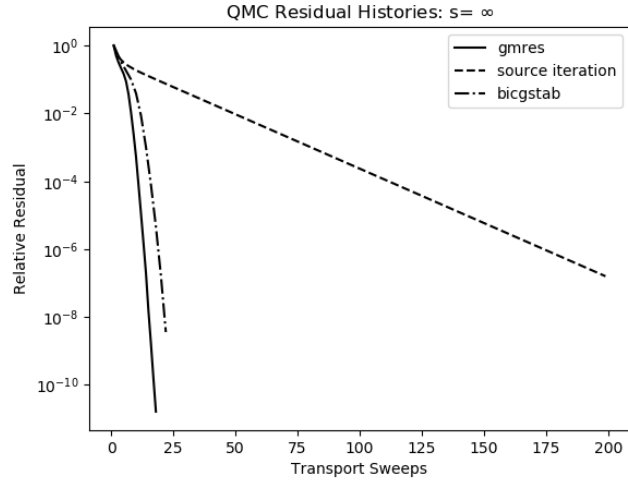


Fig. 2.  $s = \infty$

### II.C. Validation and calibration study

We conclude this section with a validation study. We compare the QMC results with the results from [1]. The results in [1] are exit distributions and are accurate to six figures. We have duplicated those results with an  $S_n$  computation on a fine angular and spatial mesh.

**Sam, Ryan, should we use more or different values of  $N$  and  $Nx$ ?**

For  $N = 1000$  and  $Nx = 100$  we obtain the cell-average fluxes from the QMC approximation. We then use a single  $S_n$  transport sweep to recover the exit distributions from the QMC cell-average fluxes. We report the results and the corresponding results from [1] in Tables I and II.

The exit distributions, as is clear from Table I can vary by five orders of magnitude. Even so, the results from QMC agree with the benchmarks to roughly two figures.

TABLE I  
Exit Distributions:  $s = 1$

$\mu$	Garcia/Siewert		QMC	
	$\psi(0, -\mu)$	$\psi(\tau, -\mu)$	$\psi(0, -\mu)$	$\psi(\tau, -\mu)$
5.00e-02	5.89664e-01	6.07488e-06	5.71197e-01	5.85487e-06
1.00e-01	5.31120e-01	6.92516e-06	5.22137e-01	6.66741e-06
2.00e-01	4.43280e-01	9.64232e-06	4.41567e-01	9.25261e-06
3.00e-01	3.80306e-01	1.62339e-05	3.81029e-01	1.54416e-05
4.00e-01	3.32964e-01	4.38580e-05	3.34673e-01	4.09691e-05
5.00e-01	2.96090e-01	1.69372e-04	2.98224e-01	1.57373e-04
6.00e-01	2.66563e-01	5.73465e-04	2.68871e-01	5.35989e-04
7.00e-01	2.42390e-01	1.51282e-03	2.44749e-01	1.42448e-03
8.00e-01	2.22235e-01	3.24369e-03	2.24583e-01	3.07431e-03
9.00e-01	2.05174e-01	5.96036e-03	2.07478e-01	5.67991e-03
1.00e+00	1.90546e-01	9.77123e-03	1.92789e-01	9.35351e-03

### III. CONCLUSION

TABLE II  
Exit Distributions:  $s = \infty$

$\mu$	Garcia/Siewert		QMC	
	$\psi(0, -\mu)$	$\psi(\tau, -\mu)$	$\psi(0, -\mu)$	$\psi(\tau, -\mu)$
5.00e-02	8.97798e-01	1.02202e-01	8.47454e-01	1.00663e-01
1.00e-01	8.87836e-01	1.12164e-01	8.52822e-01	1.10325e-01
2.00e-01	8.69581e-01	1.30419e-01	8.47710e-01	1.29064e-01
3.00e-01	8.52299e-01	1.47701e-01	8.35879e-01	1.46849e-01
4.00e-01	8.35503e-01	1.64497e-01	8.22291e-01	1.64034e-01
5.00e-01	8.18996e-01	1.81004e-01	8.08044e-01	1.80827e-01
6.00e-01	8.02676e-01	1.97324e-01	7.93459e-01	1.97336e-01
7.00e-01	7.86493e-01	2.13507e-01	7.78672e-01	2.13625e-01
8.00e-01	7.70429e-01	2.29571e-01	7.63768e-01	2.29725e-01
9.00e-01	7.54496e-01	2.45504e-01	7.48818e-01	2.45642e-01
1.00e+00	7.38721e-01	2.61279e-01	7.33889e-01	2.61361e-01

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