Comparison of Non-overlapping and Overlapping Local/Global Iteration Schemes for Whole-Core Deterministic Transport Calculation

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1. Introduction

To overcome the limitation of the conventional reactor core analysis based on isolated single-assembly lattice calculation and diffusion nodal core calculation, overlapping local/global (OLG) iteration method is proposed recently [1, 2], in which two types of local problems are considered: (1) fine-group deterministic transport model and (2) continuous-energy Monte Carlo transport model. In the case of deterministic transport model, fixed-k problem formulation is necessary and the overlapping local domain is chosen. However, as mentioned in [1], the partial current-based Coarse Mesh Finite Difference (p-CMFD) procedure [3] enables also non-overlapping local/global (NLG) iteration.

In this paper, NLG iteration is combined with p-CMFD and with CMFD (augmented with a concept of p-CMFD), respectively, and compared to OLG iteration on a 2-D test problem.

2. Two Local/Global Iteration Schemes

In local/global iteration, local transport calculation and global diffusion-like calculation are "coupled" through interface boundary condition. A detail scheme of OLG method is described in previous works [1, 2]. NLG iteration is similar to OLG, but NLG has two differing features.

2.1 Local Calculation Domain

NLG uses assembly-size domain. Each local domain is isolated in the beginning, hence it is expected that the resulting homogenized parameters are inaccurate in early iterations. On the other hand, OLG uses half-assembly overlap region, generating more accurate local homogenized parameters in early iterations.

2.2 Update of Local Boundary Condition

In the case of deterministic local problem, partial currents from global calculations are used to update the incoming angular flux at the local calculation boundary. The local problem is then solved with the updated boundary condition and fixed multiplication factor (fixed-k problem formulation). Eq. (1) shows the expression for angular flux update using partial currents available in p-CMFD:

$$\psi_{\pm n,g}^{new,local}(\vec{r}) = \frac{\psi_{\pm n,g}^{local}(\vec{r})}{\bar{J}_G^{\pm,local}} \bar{J}_G^{\pm,global}. \quad (1)$$

For OLG, local angular flux comes from the center in neighboring local domain [1, 2]. On the other hand, NLG uses local angular flux which comes from the outgoing angular flux in neighboring local domain. But, both OLG and NLG need new partial current after global calculation. The p-CMFD methodology [3] describes partial currents by

$$\begin{aligned} \bar{J}_{G,i+1/2}^{+} &= -(1/2)\tilde{D}_{G,i+1/2}\left(\bar{\phi}_{G,i+1} - \bar{\phi}_{G,i}\right) + \hat{D}_{G,i+1/2}^{+}\bar{\phi}_{G,i}, \\ \bar{J}_{G,i+1/2}^{-} &= (1/2)\tilde{D}_{G,i+1/2}\left(\bar{\phi}_{G,i+1} - \bar{\phi}_{G,i}\right) + \hat{D}_{G,i+1/2}^{-}\bar{\phi}_{G,i+1}, \end{aligned} \quad (2)$$

Hence, p-CMFD is naturally appropriate for update of angular flux at local problem boundary.

If the CMFD methodology is to be used in the global calculation, some scheme to generate partial currents is necessary, e.g., P_1-like approximation as in [4]. In this paper, incoming angular flux is modulated by neighboring coarse mesh averaged scalar flux as:

$$\psi_{+n,g}^{new,local}(\vec{r}) = \frac{\psi_{+n,g}^{local}(\vec{r})}{\bar{\phi}_{G,neighbor}^{local}} \bar{\phi}_{G,neighbor}^{global}. \quad (3)$$

Note that Eq. (3) is a special case of Eq. (1) in that it uses the second term in Eq. (2). Hence NLG with CMFD uses a p-CMFD concept in boundary condition update.

3. Numerical Results

OLG and NLG schemes are tested and compared using a test problem. The problem is a modified OECD/NEA C5G7 problem [5] with 2×2 fuel assemblies surrounded by reflector, which is shown in Fig 1. Local transport calculation is done by S_8. Seven-group to two-group condensation is performed. Error criteria are 1.0e-7 for multiplication factor and 1.0e-5 for fission source. Numerical results are shown in Table I.

As noted in Table I, most cases converge to the reference value, except for several diverging cases in NLG with CMFD. Among all the cases, the run of "NLG with p-CMFD/8×8/fission-source iteration number 1" shows best computing time performance.

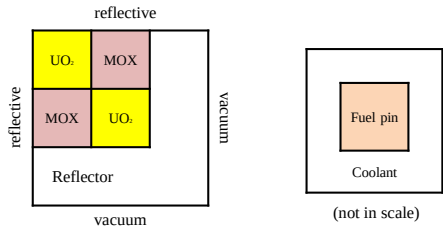

Fig 1. Core and pin configurations of test problem

As fission-source iteration number in local calculation decreases, local/global iteration number increases, but computing time is reduced. OLG needs a smaller local/global iteration number than NLG. But, NLG shows improved computing time compared to OLG. If converged, NLG with CMFD shows better computing performance than the other methods on the same conditions. But NLG with CMFD diverges if fission-source iteration number is small. The other methods based on p-CMFD provide unconditional convergence.

4. Conclusions

Non-overlapping local/global iteration with p-CMFD and CMFD global calculation is introduced and tested on a 2-D deterministic transport problem. The modified C5G7 problem is analyzed with both NLG and OLG methods and the solutions converge to the reference solution except for some cases of NLG with CMFD. NLG with CMFD gives the best performance *if* the solution converges. But if fission-source iteration in local calculation is not enough, it is prone to diverge. The p-CMFD global solver gives unconditional convergence (for both OLG and NLG).

A study of switching scheme is in progress, where NLG/p-CMFD is used as "starter" and then switched to NLG/CMFD to render the whole-core transport calculation more efficient and robust. Parallel computation is another obvious future work.

References

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Table I. Comparison results of test problem

Methods	# of coarse meshes per assembly	Fission-source iteration number in local calculation	k_{eff} value in 1st local/global iteration	Relative error of k_{eff} in 1st local/global iteration (pcm)*	Local/global iteration number	Computing time (sec)
OLG with p-CMFD	2 × 2	10	1.1342306	-2032.1	17	1657.52
		5	1.1232179	-2983.3	23	1186.48
		2	1.1102467	-4103.7	39	774.83
		1	1.0894639	-5898.8	71	692.95
	8 × 8	10	1.1508774	-594.2	10	974.89
		5	1.1485796	-792.7	11	537.48
		2	1.1469090	-937.0	15	293.56
		1	1.1425020	-1317.7	20	197.45
NLG with p-CMFD	2 × 2	10	1.1274065	-2621.5	17	551.72
		5	1.1144187	-3743.3	23	401.69
		2	1.0990423	-5071.4	39	266.09
		1	1.0867395	-6134.1	68	220.61
	8 × 8	10	1.1485918	-791.7	10	323.42
		5	1.1457501	-1037.1	12	196.61
		2	1.1432929	-1249.3	18	118.69
		1	1.1573790	-32.7	28	92.50
NLG with CMFD	2 × 2	10	1.1596019	159.3	11	352.75
		5	1.1598601	181.6	18	286.98
		2	1.1666561	768.6	38	248.94
		1	Not converged	-	Not converged	-
	8 × 8	10	1.1610975	288.5	7	225.59
		5	1.1619131	359.0	8	130.03
		2	Not converged	-	Not converged	-
		1	Not converged	-	Not converged	-

*Reference k_{eff} = 1.15775524 (whole-core seven-group S_8 calculation)