Finite Difference Method Code for Neutron Diffusion Equation

Dec 9, 2015

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Input Format

❖ IAEA Benchmark Problem INPUT

```
Options (
    Dimension 3
    MeshSize 10 10 20
    Albedo 0 0.4692 0 0.4692 0.4692 0.4692
      omega 1.5
    Method SOR
);

Geometry (
    NodeNum   17 17 19
    xNodeSize 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
    yNodeSize 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
    zNodeSize 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20

    NodeType
    5
      4 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 0
      4 2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 3 3 0
      4 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 4
      4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 4
      4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4

   Configuration
0 2 2 2 2 2 2 0 0 2 2 2 2 3 3 4 4
2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 4 4
2 2 2 2 2 2 2 2 2 2 2 2 2 3 3 4 4
2 2 2 1 1 2 2 2 2 2 2 3 3 3 3 4 4
2 2 2 1 1 2 2 2 2 2 2 3 3 3 3 4 4
2 2 2 2 2 2 2 2 2 2 2 3 3 4 4 4 4
2 2 2 2 2 2 2 2 2 2 2 3 3 4 4 4 4
0 2 2 2 2 2 2 0 0 3 3 3 3 4 4 . .
0 2 2 2 2 2 2 0 0 3 3 3 3 4 4 . .
2 2 2 2 2 2 2 3 3 3 3 4 4 4 4 . .
2 2 2 2 2 2 2 3 3 3 3 4 4 4 4 . .
2 2 2 3 3 3 3 3 3 4 4 4 4 . . . .
2 2 2 3 3 3 3 3 3 4 4 4 4 . . . .
3 3 3 3 3 4 4 4 4 4 4 . . . . . .
3 3 3 3 3 4 4 4 4 4 4 . . . . . .
4 4 4 4 4 4 4 . . . . . . . . . .
4 4 4 4 4 4 4 . . . . . . . . . .
);
```

```
CXLibrary (
    CXTableNum 5
   CXTable 1 (
      DiffCoeff   1.5E+00 4.0E-01
      SigAbs      1.0E-02 8.0E-02
      nuSigFis    0.0E+00 1.35E-01
      SigChi      1.0E-00 0.0E+00
      SigSca      0.0E-00 2.0E-02
                  0.0E-00 0.0E-00
    );
   CXTable 2 (
      DiffCoeff   1.5E+00 4.0E-01
      SigAbs      1.0E-02 8.5E-02
      nuSigFis    0.0E+00 1.35E-01
      SigChi      1.0E+00 0.0E+00
      SigSca      0.0E-00 2.0E-02
                  0.0E-00 0.0E-00
   );
   CXTable 3 (
      DiffCoeff   1.5E+00 4.0E-01
      SigAbs      1.0E-02 1.3E-01
      nuSigFis    0.0E+00 1.35E-01
      SigChi      1.0E+00 0.0E+00
      SigSca      0.0E-00 2.0E-02
                  0.0E-00 0.0E-00
   );
   CXTable 4 (
      DiffCoeff   2.0E+00 3.0E-01
      SigAbs      0.0E+00 1.0E-02
      nuSigFis    0.0E+00 0.0E+00
      SigChi      0.0E+00 0.0E+00
      SigSca      0.0E-00 4.0E-02
                  0.0E-00 0.0E-00
   );
   CXTable 0 (
      DiffCoeff   2.0E+00 3.0E-01
      SigAbs      0.0E+00 5.5E-02
      nuSigFis    0.0E+00 0.0E+00
      SigChi      0.0E+00 0.0E+00
      SigSca      0.0E-00 4.0E-02
                  0.0E-00 0.0E-00
   );
.);
```

Problem

❖ IAEA Benchmark Problem

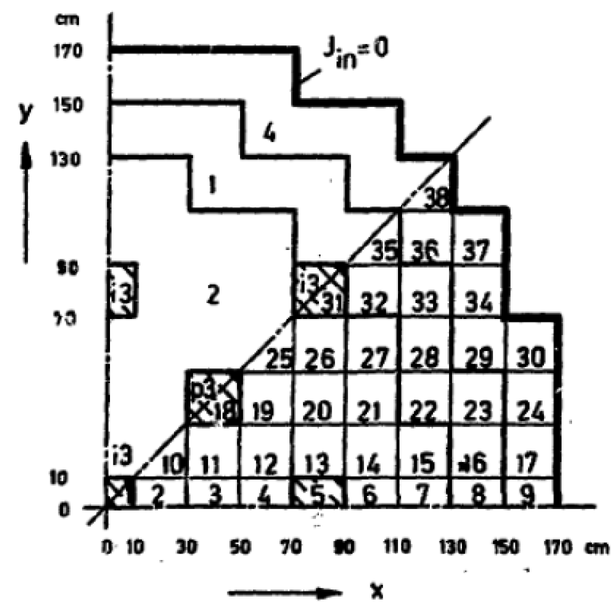
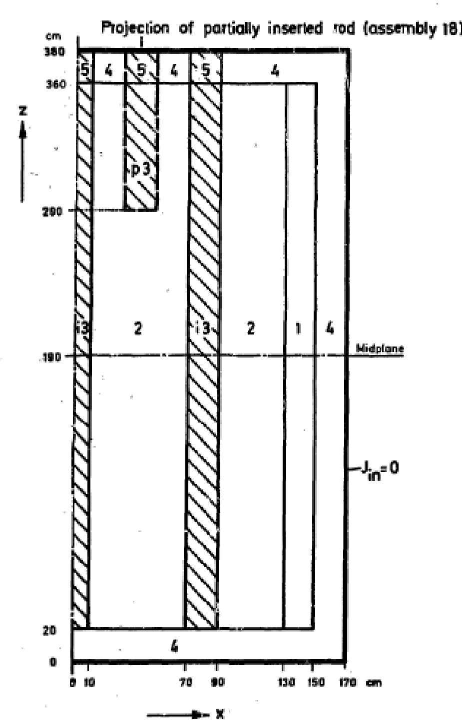


Fig. 1:
Horizontal Cross Section.
Upper Octant: Region Assignments
Lower Octant: Fuel Assembly Identification



Argonne Code Center, Benchmark Problem Book, ANL-7416, Suppl. 2, p. 277, Argonne National Laboratory (1977).

Problem

❖ IAEA Benchmark Problem

Two-group Constants

Region	D_1	D_2	$\Sigma_{1\to2}$	Σ_{a1}	Σ_{a2}	$\nu\Sigma_{f2}$	Material
1	1.5	0.4	0.02	0.01	0.08	0.135	Fuel 1
2	1.5	0.4	0.02	0.01	0.085	0.135	Fuel 2
3	1.5	0.4	0.02	0.01	0.13	0.135	Fuel 2 + Rod
4	2.0	0.3	0.04	0	0.01	0	Reflector
5	2.0	0.3	0.04	0	0.055	0	Refl. + Rod

For finite difference diffusion theory codes the following form is considered equivalent

$$\frac{\partial \phi_g}{\partial n} = -\frac{0.4692}{D_g}\phi_g$$

Argonne Code Center, Benchmark Problem Book, ANL-7416, Suppl. 2, p. 277, Argonne National Laboratory (1977).

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Numerical Results

❖ Condition

– Inner iteration : 10^{-6} for relative norm
– Outer iteration : 10^{-6} for maximum relative value

Convergence Criteria

- Inner Loop : $\frac{\|\phi^{(t)}-\phi^{(t-1)}\|}{\|\phi^{(t-1)}\|} < 10^{-6}$
- Outer Loop : $\max\left(\frac{\phi^{(t)}-\phi^{(t-1)}}{\phi^{(t-1)}}\right) < 10^{-6}$

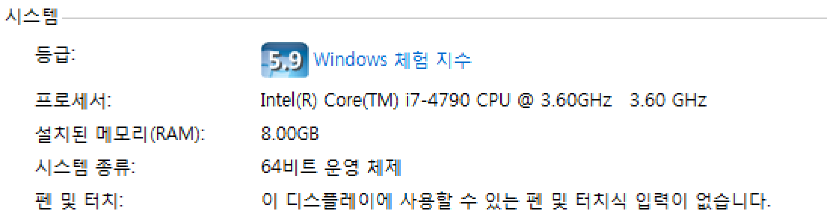
Numerical Results

❖ IAEA Benchmark Problem

Meshpoints	Multiplication Factor			
	Reference	Jacobi	GS	SOR
17×17×19	1.02913	1.02913	1.02913	1.02913
34×34×38	1.02864	1.02864	1.02864	1.02864
68×68×76	1.02887	1.02887	1.02887	1.02887

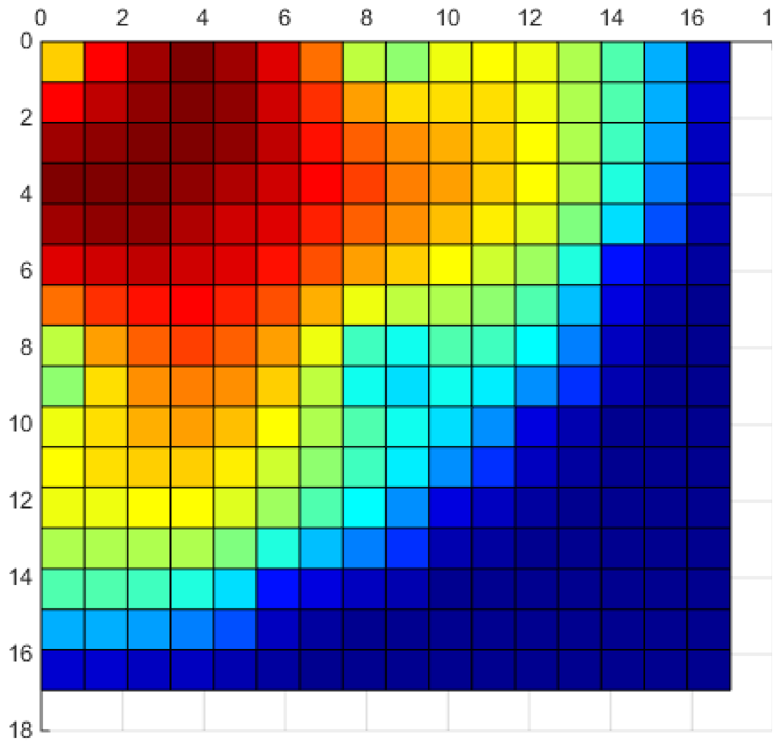
Numerical Results

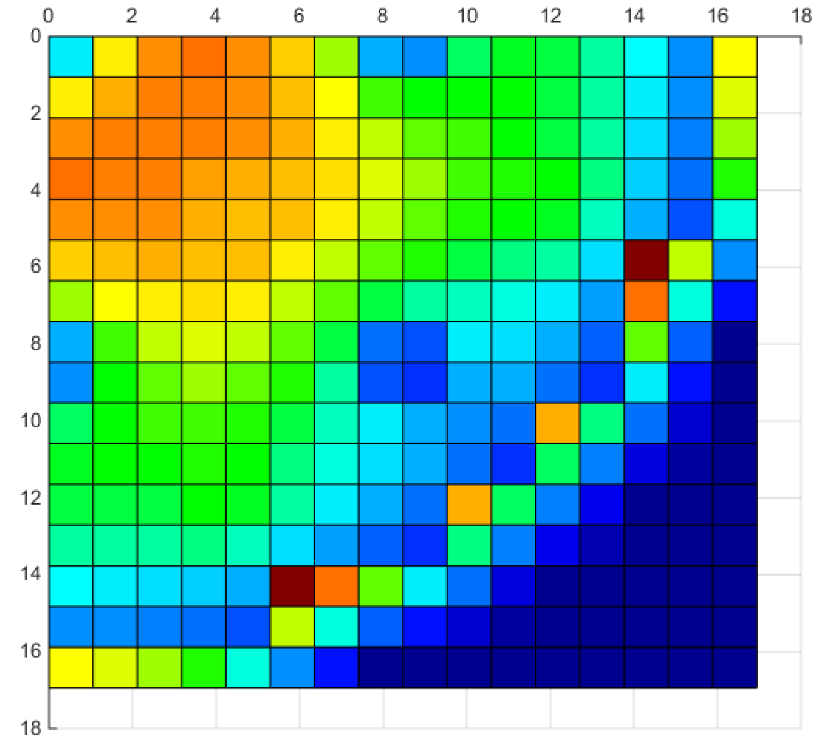
❖ IAEA Benchmark Problem



Meshpoints	Calculation time[s]			
	Reference	Jacobi	GS	SOR (w=1.5)
17×17×19	-	3.2	1.8	0.9
34×34×38	-	29.4	16.4	6.8
68×68×76	-	514.2	303.8	124.9

Numerical Results





Neutron flux distribution of Group 1 (left) and Group 2 (right)

Parallel programing with OpenMP

❖ OpenMP with Visual Studio

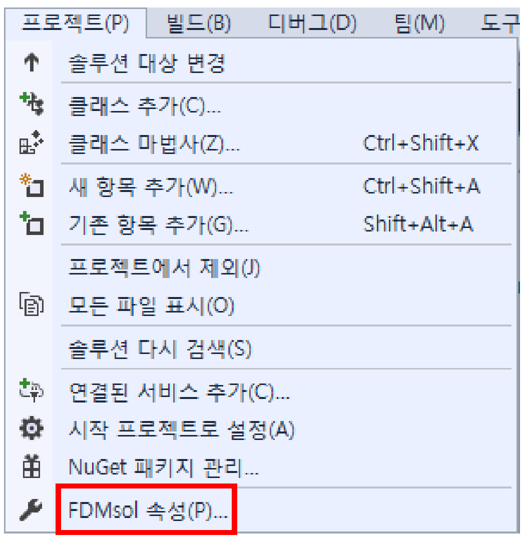
Visual C++ supports the OpenMP 2.0 standard.

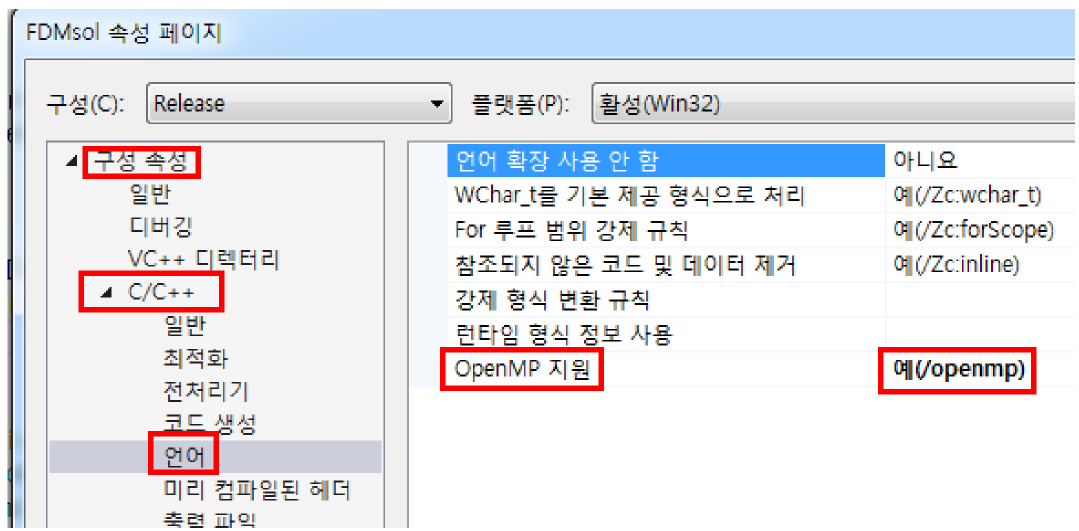
To enable OpenMP on a Windows OS system using Microsoft Visual Studio*:

① Select Project>Properties

② Specify the Configuration Properties for C++ project

③ Add #include <omp.h> on the code.





Parallel programing with OpenMP

❖ IAEA Benchmark Problem

시스템

등급:	5.9 Windows 체험 지수
프로세서:	Intel(R) Core(TM) i7-4790 CPU @ 3.60GHz 3.60 GHz
설치된 메모리(RAM):	8.00GB
시스템 종류:	64비트 운영 체제
펜 및 터치:	이 디스플레이에 사용할 수 있는 펜 및 터치식 입력이 없습니다.

Number of Threads : 2

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	3.2	1.8	1.9	0.9	1.0
34×34×38	29.4	23.7	16.4	14.4	6.8	6.2
68×68×76	514.2	471.1	303.8	247.1	124.9	116.7

Parallel programing with OpenMP

❖ IAEA Benchmark Problem

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펜 및 터치:	이 디스플레이에 사용할 수 있는 펜 및 터치식 입력이 없습니다.

Number of Threads : 3

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	3.3	1.8	2.1	0.9	1.6 (w=1.2)
34×34×38	29.4	24.2	16.4	13.6	6.8	6.2
68×68×76	514.2	448.3	303.8	263.31	124.9	109.4

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Parallel programing with OpenMP

❖ IAEA Benchmark Problem

시스템

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시스템 종류:	64비트 운영 체제
펜 및 터치:	이 디스플레이에 사용할 수 있는 펜 및 터치식 입력이 없습니다.

Number of Threads : 4

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	3.3	1.8	2.1	0.9	1.1
34×34×38	29.4	22.8	16.4	13.3	6.8	7.3
68×68×76	514.2	440.613	303.8	257.56	124.9	113.3

Parallel programing with OpenMP

❖ IAEA Benchmark Problem

시스템

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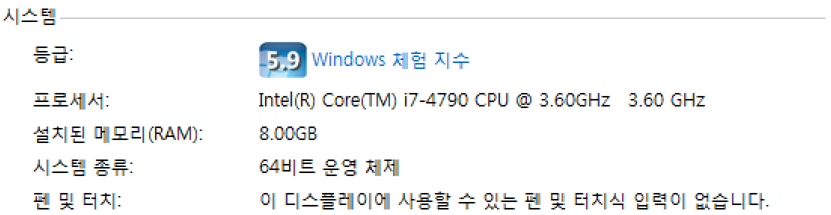
시스템 종류:	64비트 운영 체제
펜 및 터치:	이 디스플레이에 사용할 수 있는 펜 및 터치식 입력이 없습니다.

Number of Threads : 5

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	3.9	1.8	2.7	0.9	2.2 (w=1.2)
34×34×38	29.4	23.6	16.4	14.5	6.8	6.9
68×68×76	514.2	448.8	303.8	264.6	124.9	116.7

Parallel programing with OpenMP

❖ **IAEA Benchmark Problem**



Number of Threads : 6

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	3.8	1.8	2.4	0.9	1.4
34×34×38	29.4	24.1	16.4	14.2	6.8	8.27
68×68×76	514.2	440.1	303.8	267.0	124.9	118.8

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Parallel programing with OpenMP

❖ IAEA Benchmark Problem

시스템

등급:	5.9 Windows 체험 지수
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설치된 메모리(RAM):	8.00GB
시스템 종류:	64비트 운영 체제
펜 및 터치:	이 디스플레이에 사용할 수 있는 펜 및 터치식 입력이 없습니다.

Number of Threads : 7

Meshpoints	Calculation time[s]					
	Jacobi		GS		SOR (w=1.5)	
	Serial	Parallel	Serial	Parallel	Serial	Parallel
17×17×19	3.2	4.5	1.8	3.6	0.9	2.2 (w=1.2)
34×34×38	29.4	25.2	16.4	16.0	6.8	8.2
68×68×76	514.2	495.5	303.8	293.0	124.9	126.6

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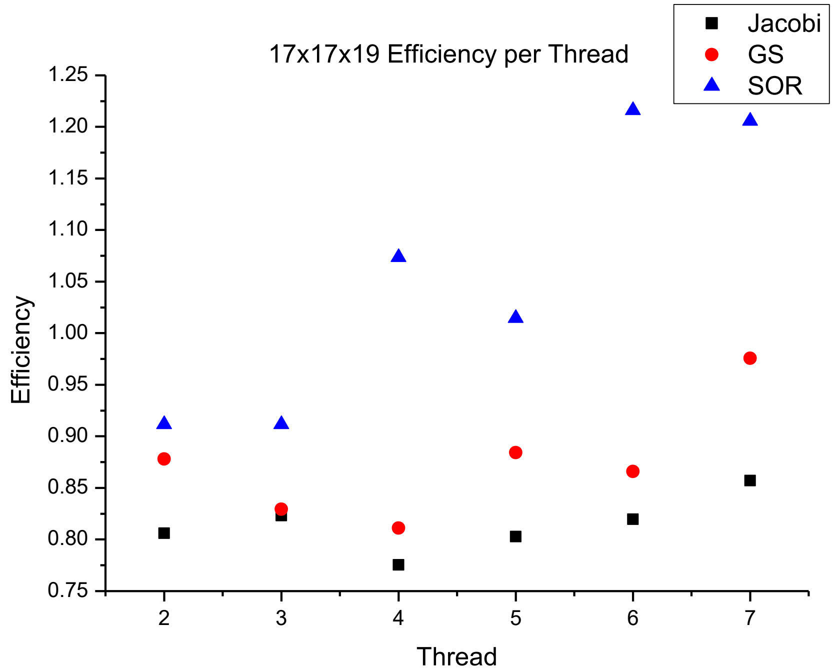
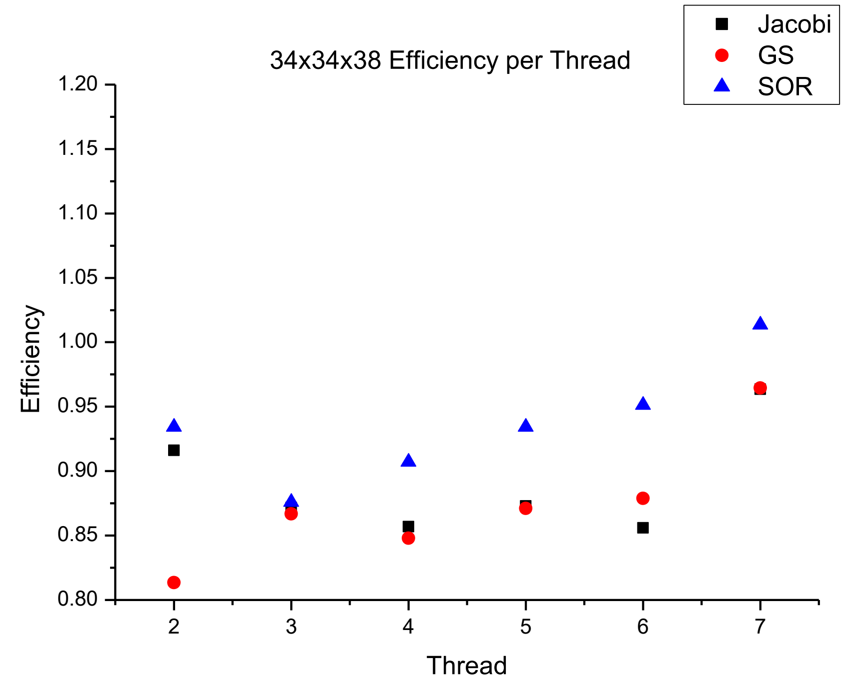
Parallel programing with OpenMP

❖ Calculation Efficiency

$$\text{Calculation Efficiency} = \frac{\text{serial calculation time}}{\text{parallel calculation time}}$$





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