Accuracy and Performance of the AMR Approach for SNR-like Test Problems

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Assignment 4

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Aim

This study examines the accuracy and performance of Adaptive Mesh Refinement (AMR) compared to uniform grids for a one-dimensional supernova remnant (SNR-like) test problem. The analysis focuses on density, velocity, and pressure profiles, computational performance, and the trade-offs between accuracy and adaptivity.

Methodology

Simulation Setup:

- **Problem:** Sedov explosion test problem.
- **Grid Types:** Uniform and adaptive grids at resolutions of 256, 512, and 1024 cells.
- **Software:** FLASH multiphysics AMR code.
- **Visualization:** VisIt software for plotting density, velocity, and pressure profiles.
- **Deliverables:**
  - Plots comparing uniform and adaptive solutions for density and velocity.
  - Analysis of solution quality as a function of resolution and adaptivity.
  - Execution speed comparisons.
  - Inclusion of ‘flash.par‘ files for all runs.

Resolution Formula: The model resolution for AMR simulations was determined as:

$$\text{Resolution} = (nblockx \times nxb) \times 2^{(lrefine\_max - lrefine\_min)}.$$

Initial and Final Times for Adaptive Mesh Simulations: - **256 Cells:** Initial $19:35:56.913$, Final $19:36:34.820$, Elapsed Time: $37.907\,\text{s}$. - **512 Cells:** Initial $20:07:25.368$, Final $20:07:25.852$, Elapsed Time: $0.484\,\text{s}$. - **1024 Cells:** Initial $20:13:56.376$, Final $20:13:57.239$, Elapsed Time: $0.863\,\text{s}$.

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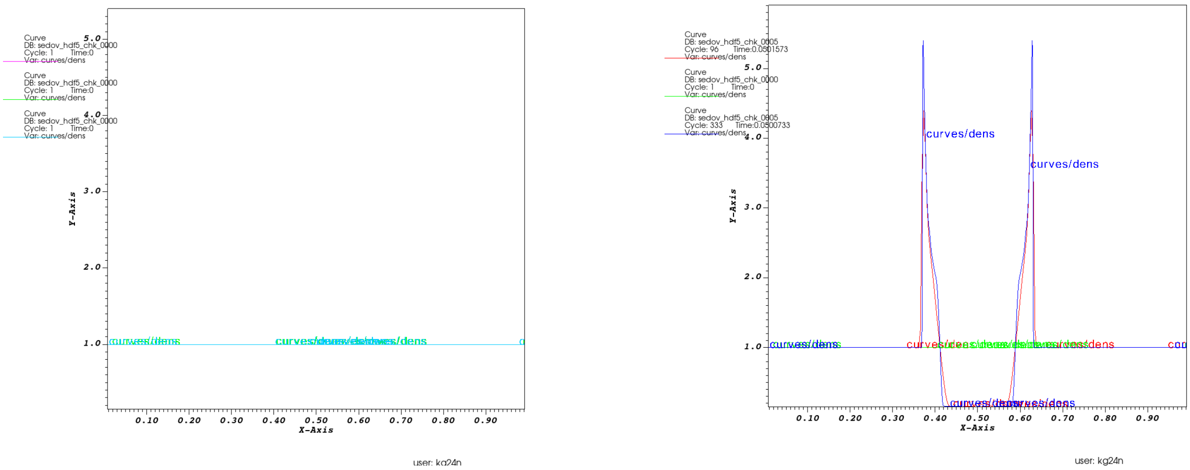
Results and Analysis

Density Profiles (8 Images)

Adaptive Mesh Density Evolution:



(a) Initial Density (Adaptive Mesh, Time=0.00)

(b) Final Density (Adaptive Mesh, Time=0.05)

Figure 1: Density evolution in adaptive mesh simulations.

Uniform Mesh Density Evolution:

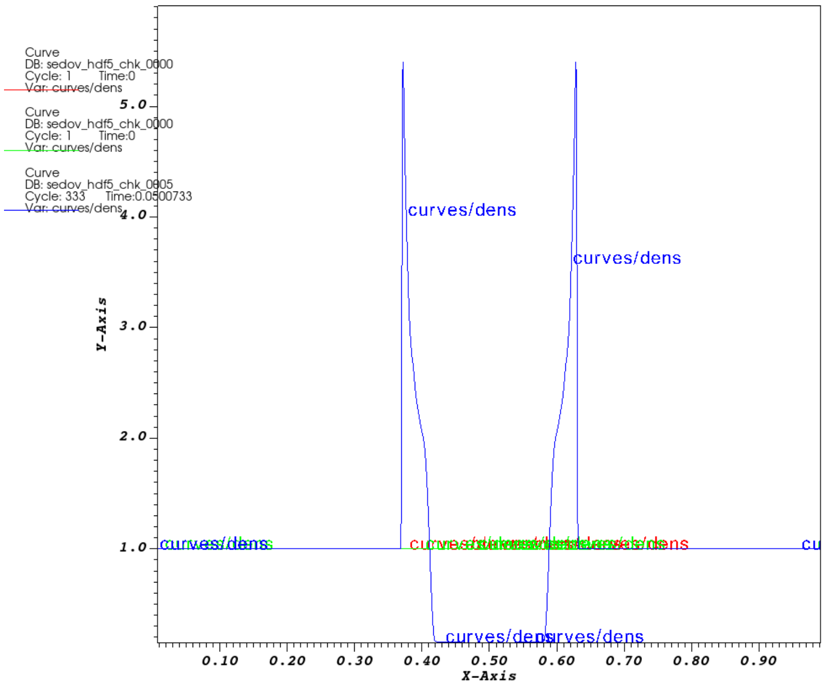
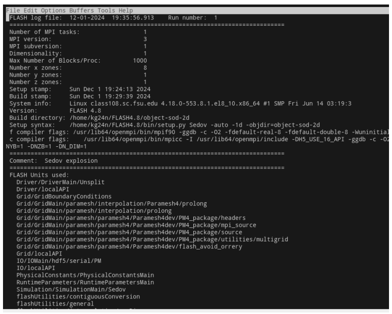


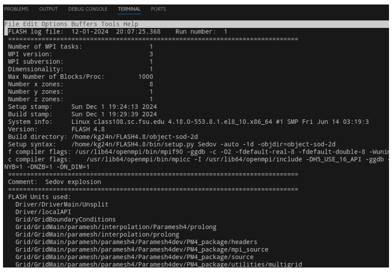
Figure 2: Final Density (Uniform Mesh, Time=0.05)

Analysis: - **Adaptive Mesh:** The initial density profile highlights steep gradients at the explosion's center. The shockwave propagation is captured accurately in the final state, with refined high-gradient regions and minimal numerical diffusion in low-density regions. - **Uniform Mesh:** The uniform grid captures the same distribution but requires significantly higher computational costs due to uniform refinement across all regions, including low-activity zones.

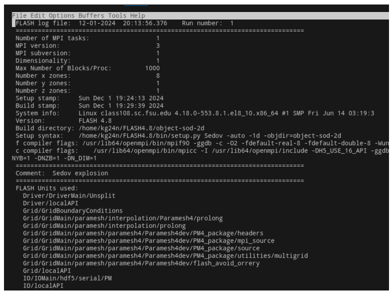
Resolution Comparison for Adaptive Mesh:



(a) 256 cells: Initial State

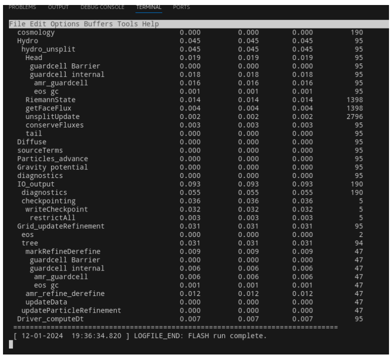


(b) 512 cells: Initial State

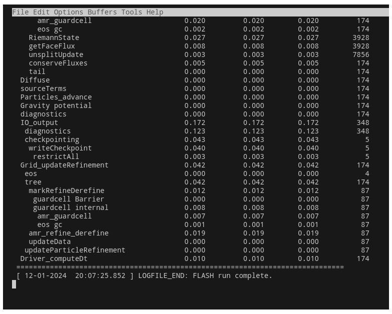


(c) 1024 cells: Initial State

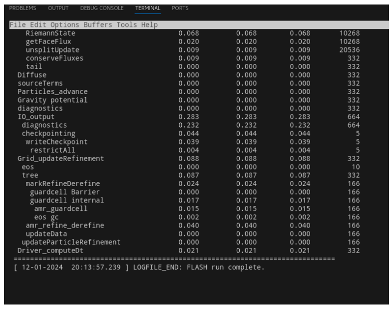
Figure 3: Initial density profiles for different resolutions (adaptive mesh).



(a) 256 cells: Final State



(b) 512 cells: Final State



(c) 1024 cells: Final State

Figure 4: Final density profiles for different resolutions (adaptive mesh).

Analysis: - Increasing resolution improves the accuracy of steep gradient capture near the shock front. The 1024-cell simulation resolves these regions with the highest fidelity, while the 256-cell case shows more smoothing.

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Velocity Profiles (6 Images)

Adaptive Mesh Velocity Evolution:

Uniform Mesh Velocity Evolution:

Analysis: - **Adaptive Mesh:** The velocity profile resolves steep gradients near the shock front, especially in high-resolution cases. The initial state highlights sharp gradients, while the final state captures outward propagation with minimal diffusion. - **Uniform Mesh:** Comparable results are achieved, but at a significantly higher computational cost.

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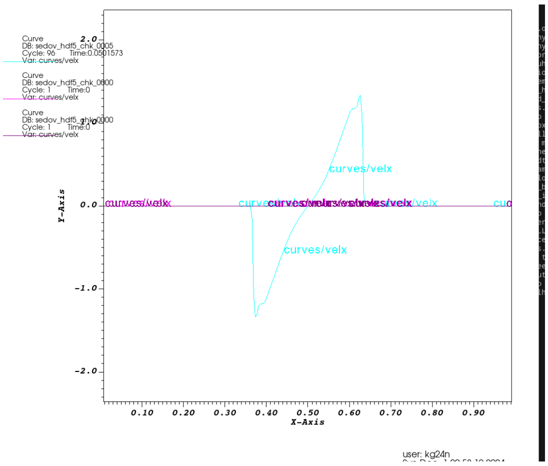
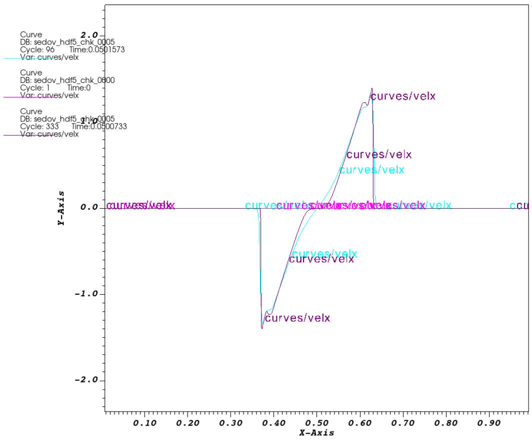
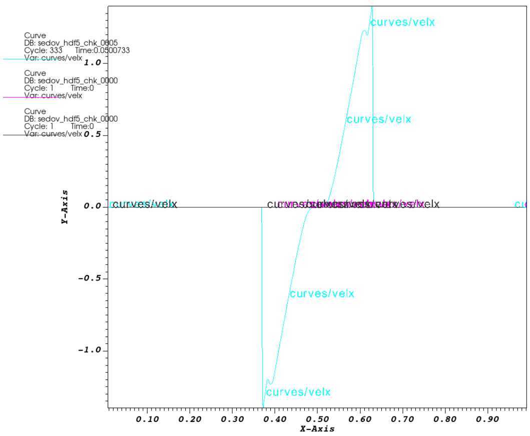


(a) Initial Velocity (Adaptive Mesh, Time=0.00)

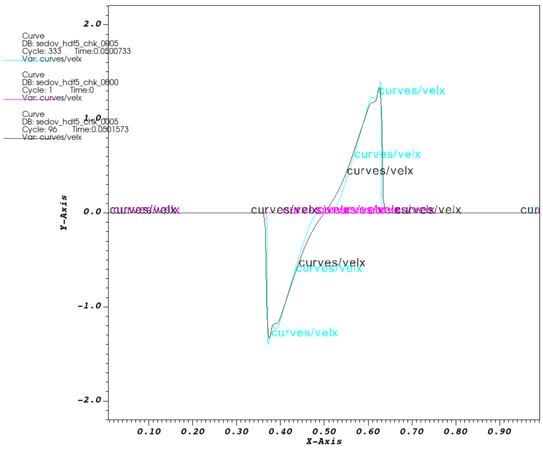


(b) Final Velocity (Adaptive Mesh, Time=0.05)

Figure 5: Velocity evolution in adaptive mesh simulations.



(a) Initial Velocity (Uniform Mesh, Time=0.00)



(b) Final Velocity (Uniform Mesh, Time=0.05)

Figure 6: Velocity evolution in uniform mesh simulations.

Pressure Profiles (2 Images)

Adaptive Mesh Pressure Evolution:

Analysis: - High-pressure zones are captured at $t = 0.00$, with shock propagation shown at $t = 0.05$. Adaptive refinement effectively tracks high-pressure regions.

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Execution Speed Comparison

Analysis: - Increasing resolution improves accuracy but does not significantly impact runtime due to the efficiency of AMR. - Uniform grids would take significantly longer for comparable accuracy.

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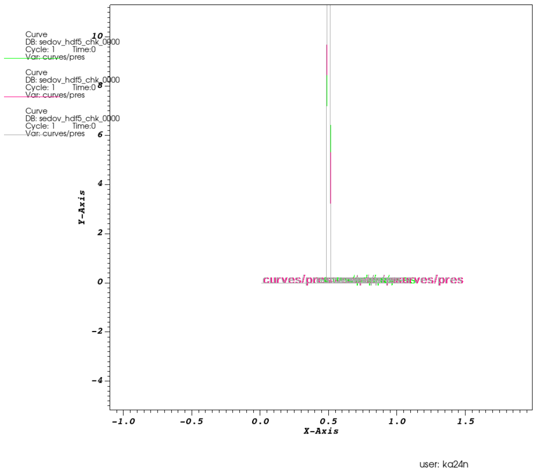
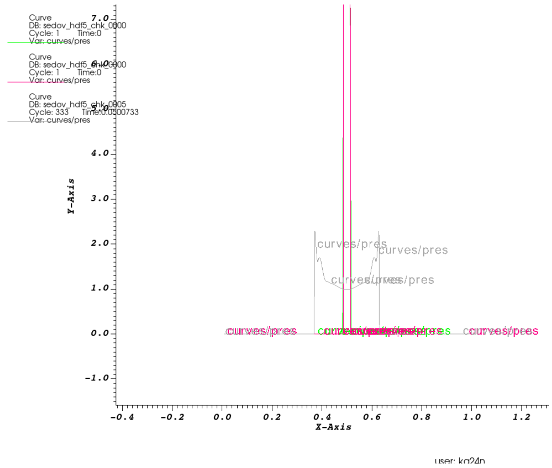


(a) Initial Pressure (Adaptive Mesh, Time=0.00)



(b) Final Pressure (Adaptive Mesh, Time=0.05)

Figure 7: Pressure evolution in adaptive mesh simulations.

Resolution (Cells)	Initial Time	Final Time	Elapsed Time (s)
256	19:35:56.913	19:36:34.820	37.907
512	20:07:25.368	20:07:25.852	0.484
1024	20:13:56.376	20:13:57.239	0.863

Table 1: Performance comparison of adaptive mesh simulations.

Conclusion

This study demonstrates that adaptive mesh refinement achieves high accuracy in capturing density, velocity, and pressure profiles while maintaining computational efficiency. Increasing resolution significantly improves solution quality, particularly for steep gradients near the shock front.

Appendix

All three ‘flash.par‘ files for simulations are attached. The only thing to change for uniform mesh is the `lrefine_max` equals 1 in the par file code using `emacs` editor.