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Integration of Reverse Monte-Carlo Ray Tracing within Uintah

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This research was sponsored by the National Nuclear Security Administration under the Accelerating Development of Retrofitable CO2 Capture Technologies through Predictivity program through DOE Cooperative Agreement DE-NA0000740

Deliverables

- Year 1: Proof-of-concept design for solving the RTE using RMCRT within ARCHES
- Year 2: Demonstration of a fully-coupled problem using RMCRT within ARCHES.

  Scalability demonstration.
- Year 3: Full burner scale V&V/UQ demonstration using RMCRT.

Background

- Reverse Monte-Carlo Ray Tracing is an *all-to-all* method.

- All geometry information and radiative properties for the entire domain must reside in **each** processor's memory*.
  Very restrictive

* Xiaojing Sun. Reverse Monte Carlo Ray-Tracing For Radiative Heat Transfer in Combustion Systems. PhD Dissertation, University of Utah, 2009.

Approach

- Utilize AMR infrastructure.
- Multiple levels at different grid resolutions.
- RMCRT calculations on the coarse regions or levels.

(3 double precision arrays on a
250^3 domain = 375 Mbytes
500^3 domain = 3 Gbytes)

Approach

CFD: Always computed on the finest level,uniform cell spacing

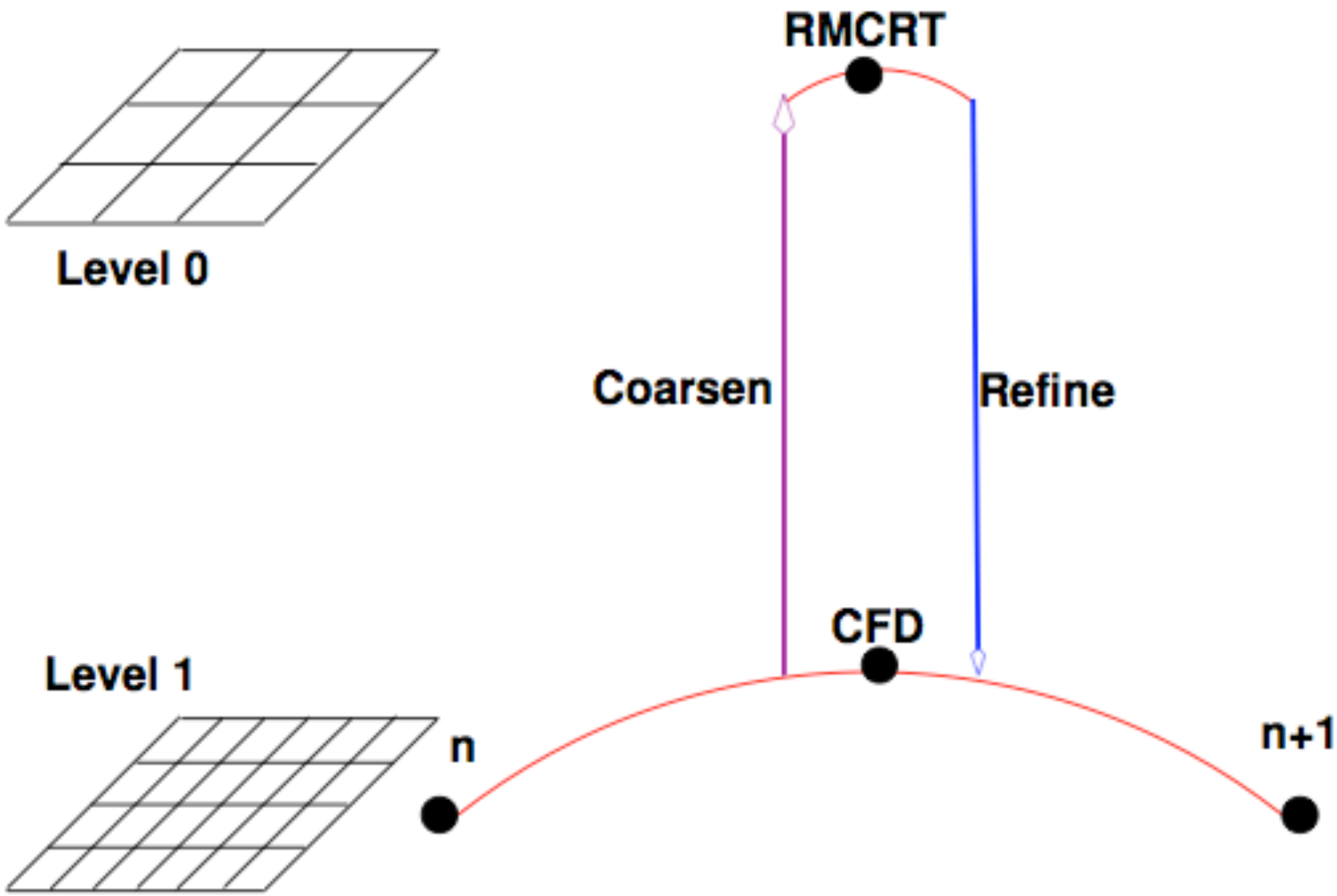
RMCRT:

2 Level: RMCRT on a coarse level, CFD on a fine level.

“Data Onion”: RMCRT & CFD on fine level, data accessed from other coarse levels.

2 Levels

2 Levels



2 Levels

<u>Advantages:</u>

- Simple
- Multi-level infrastructure already exists.
- Previous work suggests that this may be sufficient accurate for pool fires*.

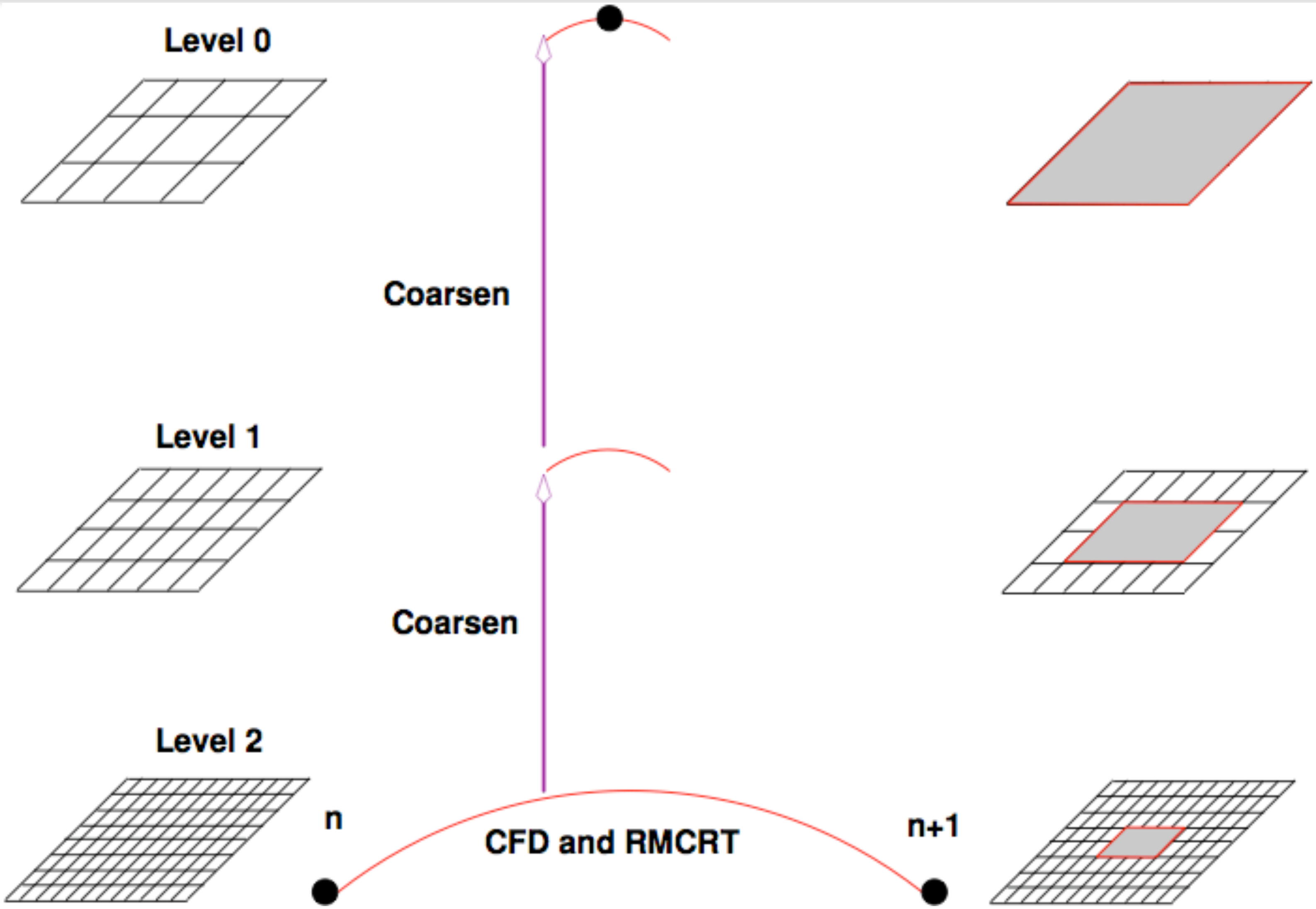
<u>Disadvantages:</u>

- Accuracy (maybe).

Gautham Krishnamoorthy. Predicting Radiative Heat Transfer in Parallel Computations of Combustion. PhD Dissertation, University of Utah, 2005.

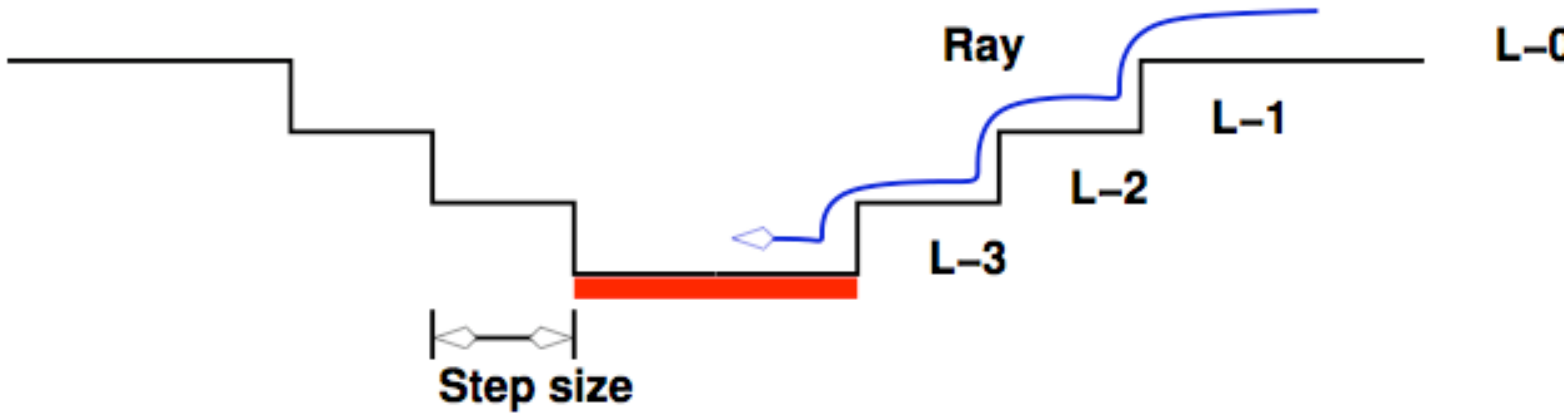
Data Onion

3-Levels



Data Onion

1D



User inputs:

- Number of levels
- Refinement ratio between levels
- Step size
- Size of fine level patch

Data Onion

Advantages:

- Increased accuracy over 2 levels

Disadvantages:

- Increased complexity
- Coarsening data multiple times
- More expensive (maybe?).

Implementation Plan

Develop in a light weight testbed component.

<u>Advantages</u>

- Rapid testing of 2-level and *data onion* schemes.
- Scalability/performance studies focus on RMCRT tasks.
- Encapsulate verification code, no pollution in ARCHES
- Forces RMCRT tasks to be portable.

Status: Completed

- ✓ RMCRT tasks within the test-bed (single level, multipatch patch)
- ✓ 90% Complete: Implementation of coarsening & refining code
- ✓ Improved portability of RMCRT tasks.
- ✓ 95% Complete: Integration of RMCRT tasks within ARCHES (single level, multipatch)

Status: Work in Progress

RMCRT: Single Level

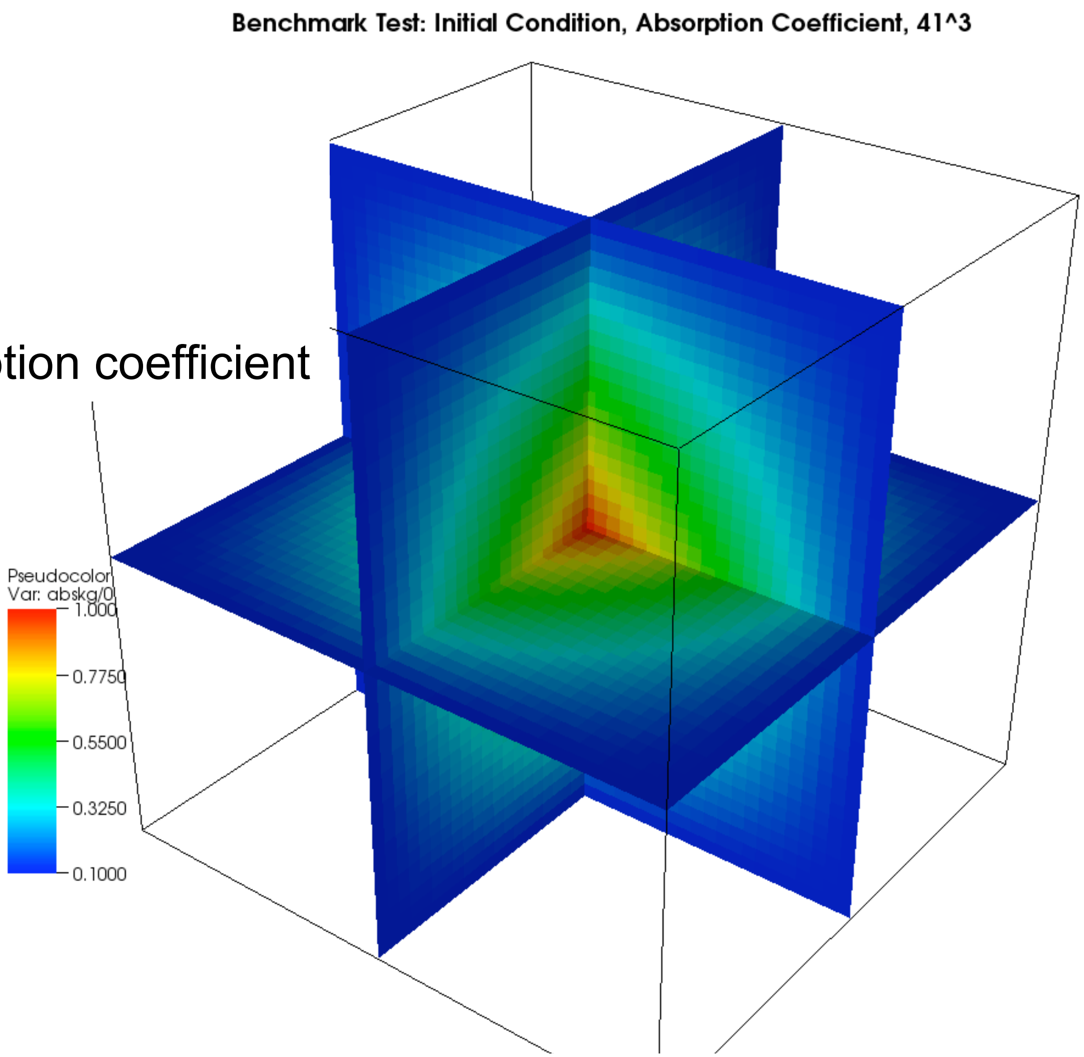
- Verification
- Serial performance
- Scalability studies
- New: Testing hybrid MPI-threaded task scheduler.

Benchmark Problem

Initial Conditions:

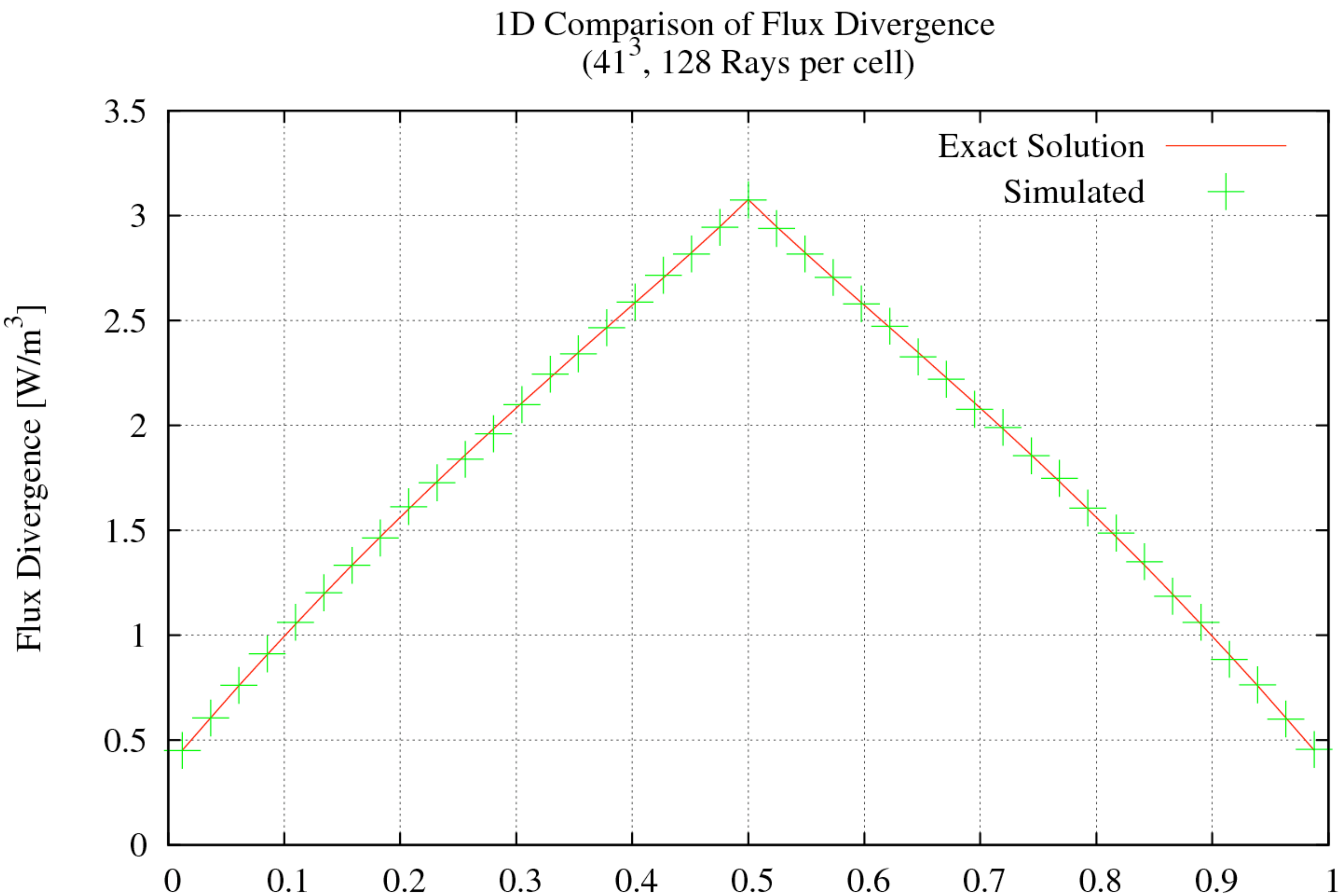
- Uniform temperature field

- Analytical function for absorption coefficient



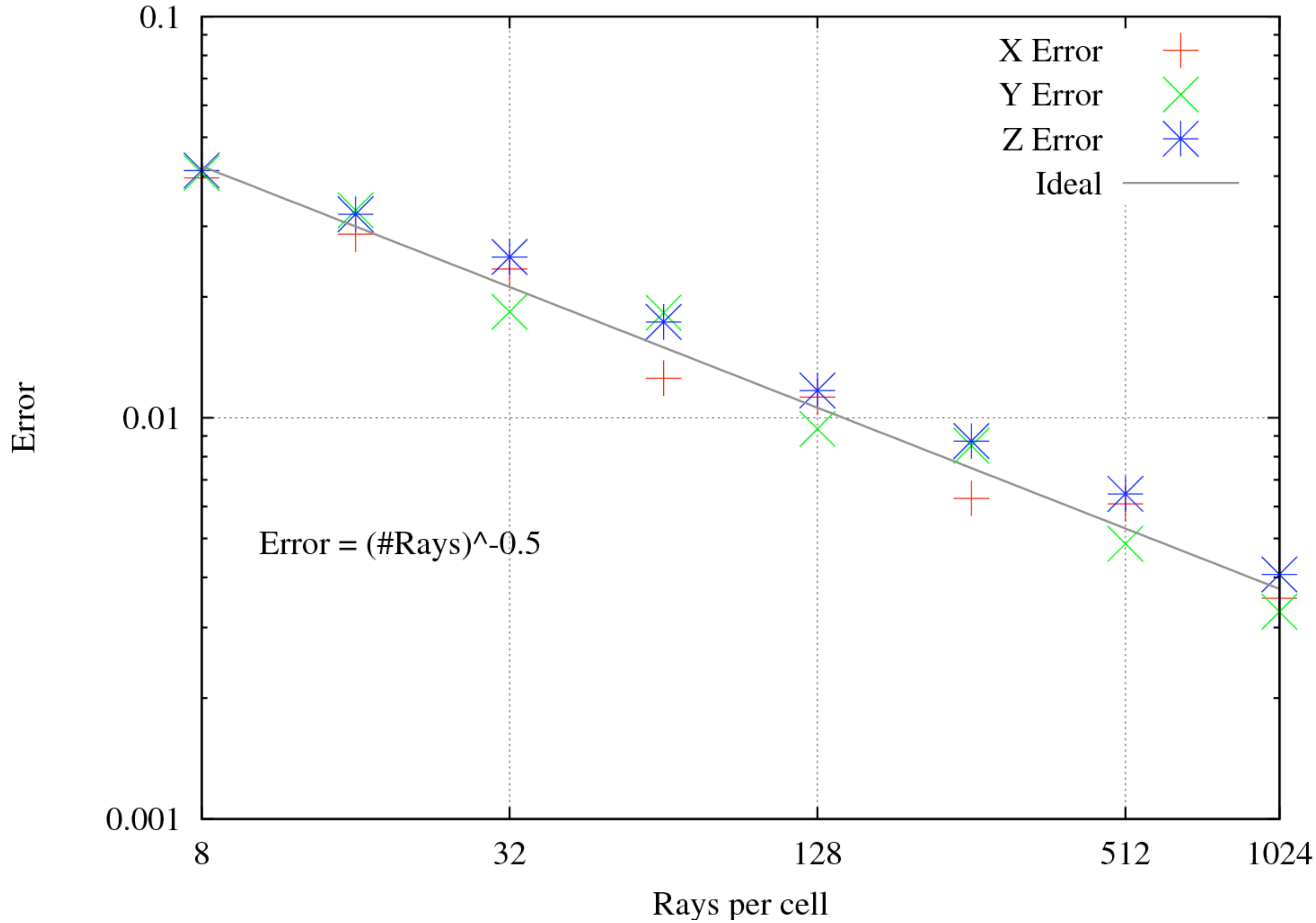
S. P. Burns and M.A Christon. Spatial domain-based parallelism in large-scale, participating-media, radiative transport applications. Numerical Heat Transfer, Part B, 31(4):401-421, 1997.

Verification



S. P. Burns and M.A Christon. Spatial domain-based parallelism in large-scale, participating-media, radiative transport applications. Numerical Heat Transfer, Part B, 31(4):401-421, 1997.

Verification



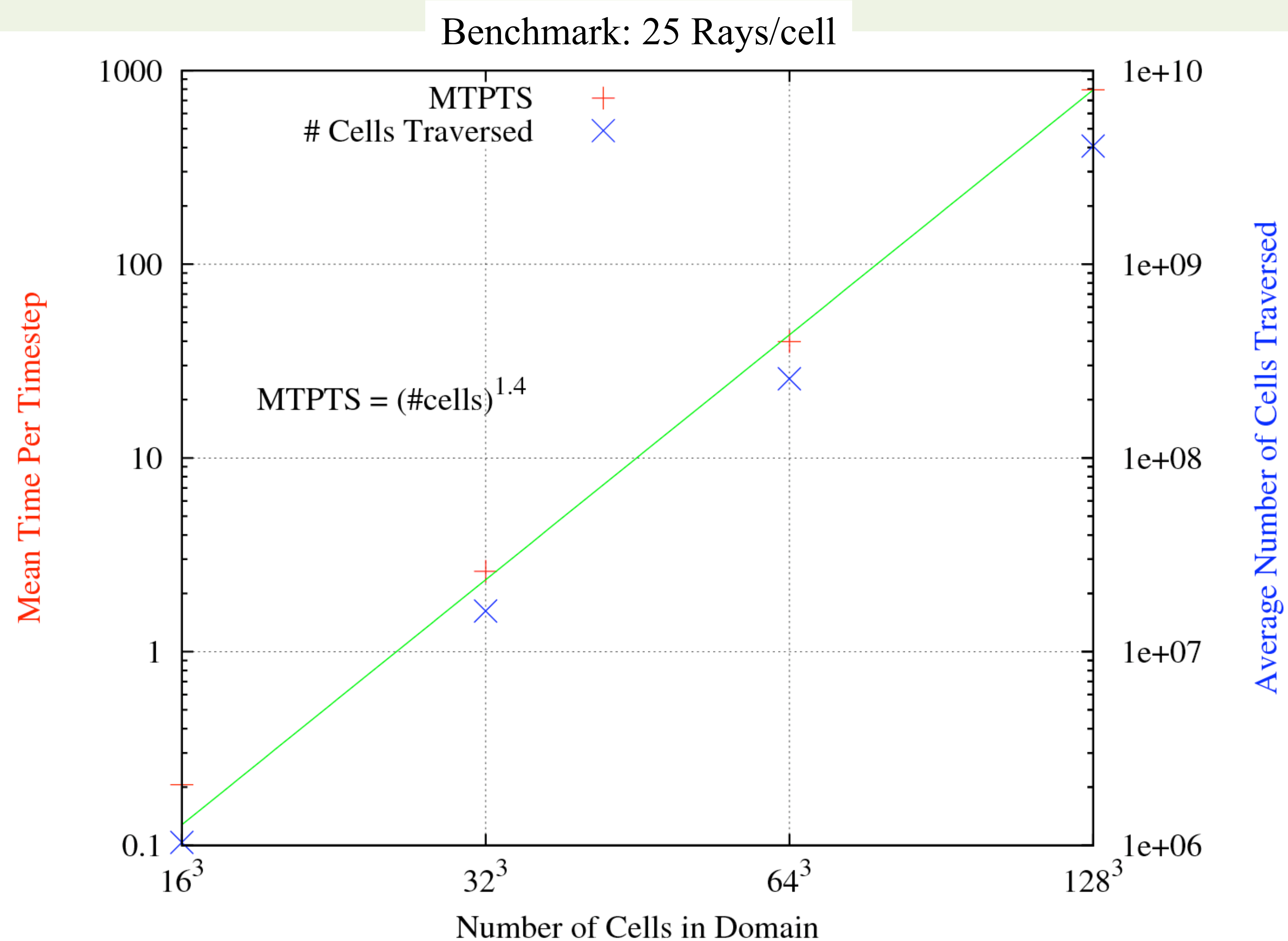
Serial Performance 1 Level

- Cost = f(#rays, Grid Cells$^{1.4\text{-}1.5}$ communication….)

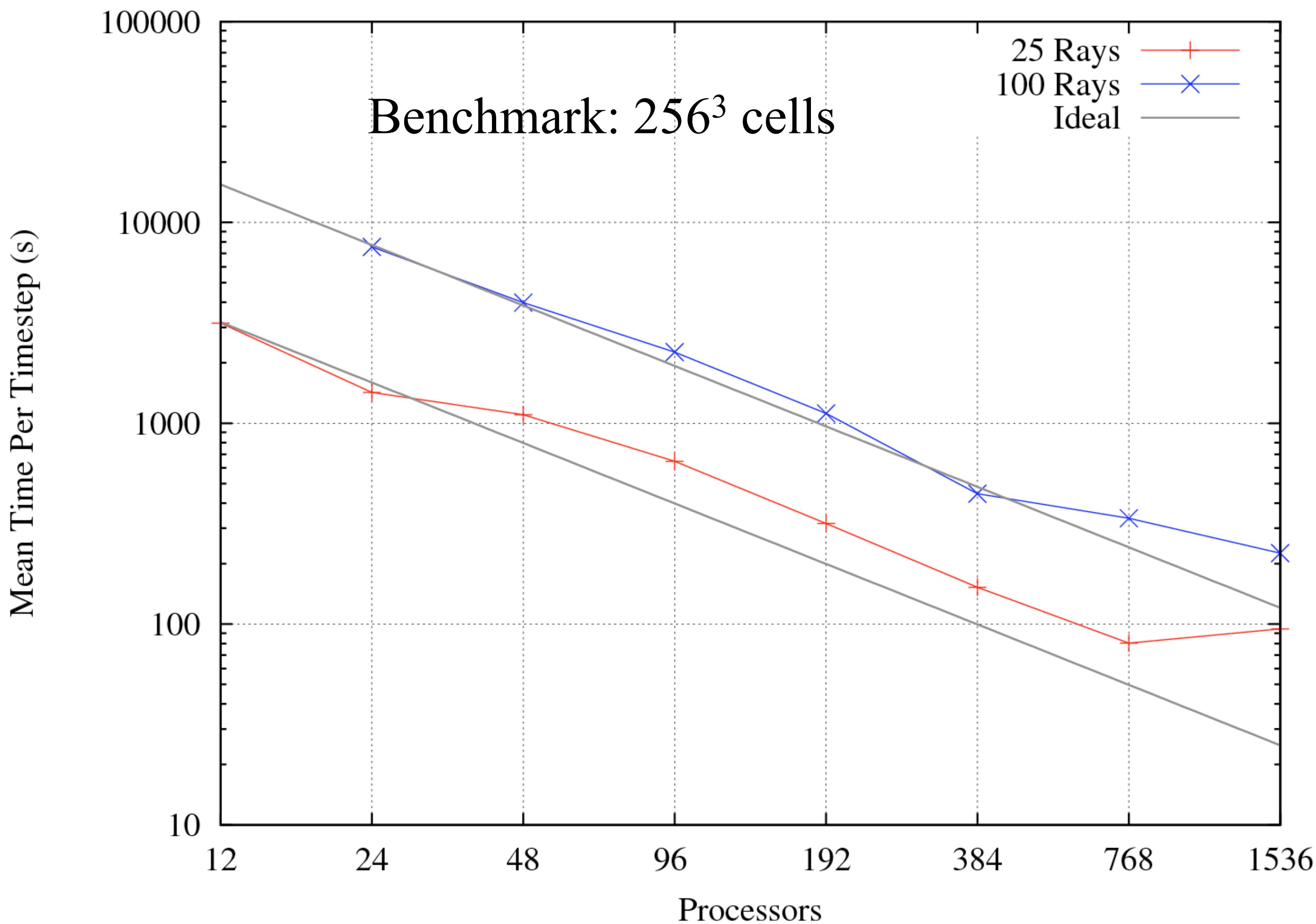
- Linear with number of rays, as expected.

- Doubling the grid resolution (8 X grid cells) = 20ish X increase in cost.

Serial Performance 1 Level



Scaling 1Level



Hybrid MPI-threaded Task Scheduler

Leverage the scalability work of Dr. Berzin's team*.

Default MPI Task Scheduler:

Data duplication on each MPI process.
(neighboring patches, neighboring tasks and ghost data)

1 MPI process per core.

*Q. Meng, M. Berzins, and J. Schmidt, *Using hybrid parallelism to improve memory use in uintah*, Proceeding of the Teragrid 2011.

Hybrid MPI-threaded Task Scheduler

Hybrid MPI-threaded Task Scheduler*:

- MPI and threads.
- 1 MPI process per node.
- 1 thread/core and threads can share data.
- Meng et al., showed a memory reduction of

  13.5Gb -> **1GB** per node (12 cores/node).

  2 material CFD problem, 2048^3 cells, on 110592 cores of Jaguar
- Interconnect drivers and MPI software must be threadsafe.

*Q. Meng, M. Berzins, and J. Schmidt, *Using hybrid parallelism to improve memory use in uintah*. In Proceeding of the Teragrid 2011.

Status: Pending

- Head to head comparison of RMCRT with Discrete Ordinates Method.

  Accuracy versus computational cost.

- Grid convergence study.

- Implement 2-L RMCRT in test-bed component (easy)

  Accuracy versus refinement ratio studies

  Scalability Studies

Status: Pending

- Implement 2-L RMCRT in ARCHES.

- Implement RMCRT with a *data onion* in the test-bed.

  Accuracy versus number of levels, refinement ratio, size of fine patch.

  Scalability Studies

Summary

Year 1: Proof-of-concept design for solving the RTE using RMCRT within ARCHES/Uintah framework.

Year 2: Demonstration of a fully-coupled problem using RMCRT within ARCHES.

Scalability demonstration.