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# Fault Tolerance Using Lower Fidelity Data in Adaptive Mesh Applications

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# Background and Motivation

- Much of the focus in applications fault tolerance is on checkpoint-restart
- Most large scale scientific applications already use that for other purposes
  - Batch queues and a simulation needing more than one slot to complete
  - Need for in-flight change in parameters
  - Exploring more than one path in the middle of evolution
  - Recovery in relatively rare instances at the moment
- The recovery part is expensive relative to the rest of the simulation cost
  - There is no way of telling whether the recovery was triggered by a non-critical fault or a critical one
- It should be possible to do in-flight recovery from a non-critical fault

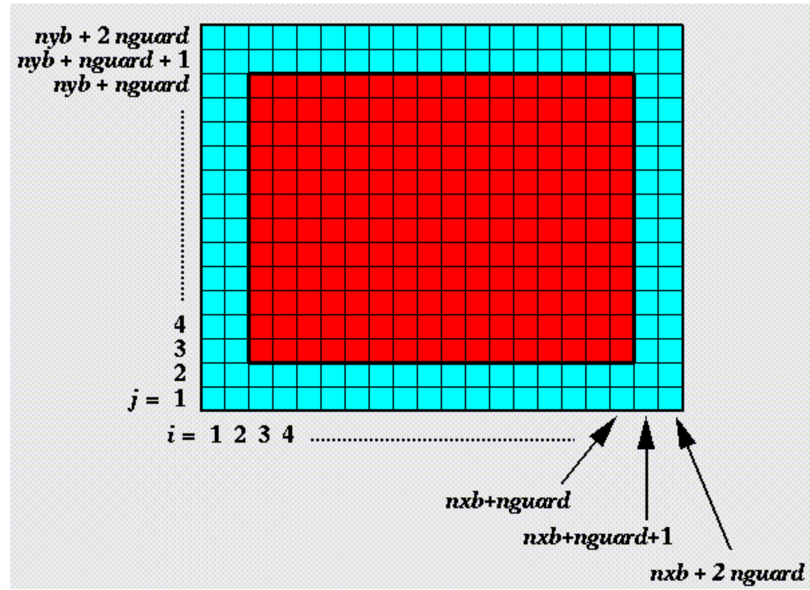
This work explores whether there is a class of faults that can be classified as non-critical in the context of AMR applications, and if so can one recover from them in-flight

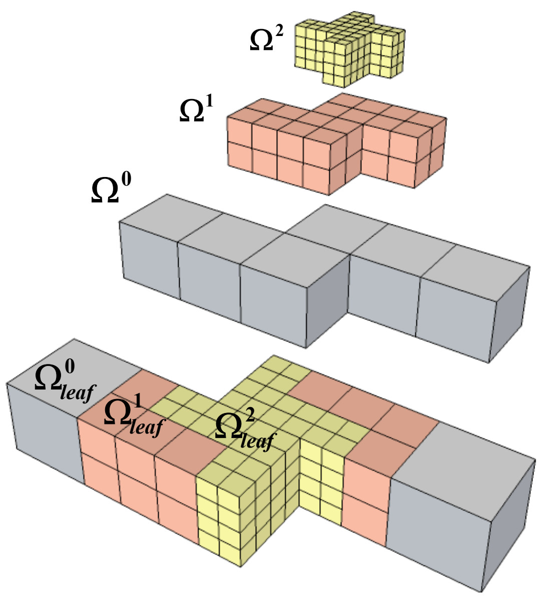
# Outline

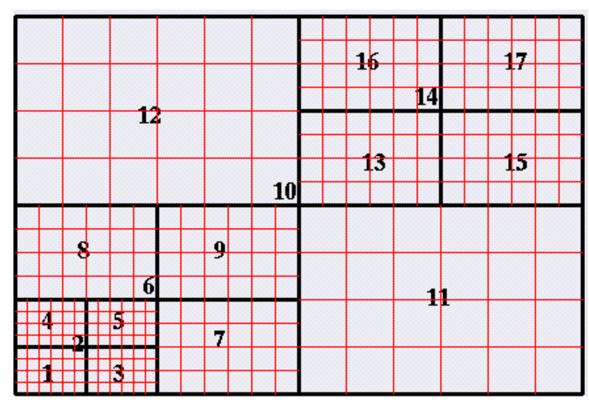
- **Block Structured AMR**
- Algorithm
- Test Cases
- Results
- Future Directions

# Block Structured AMR

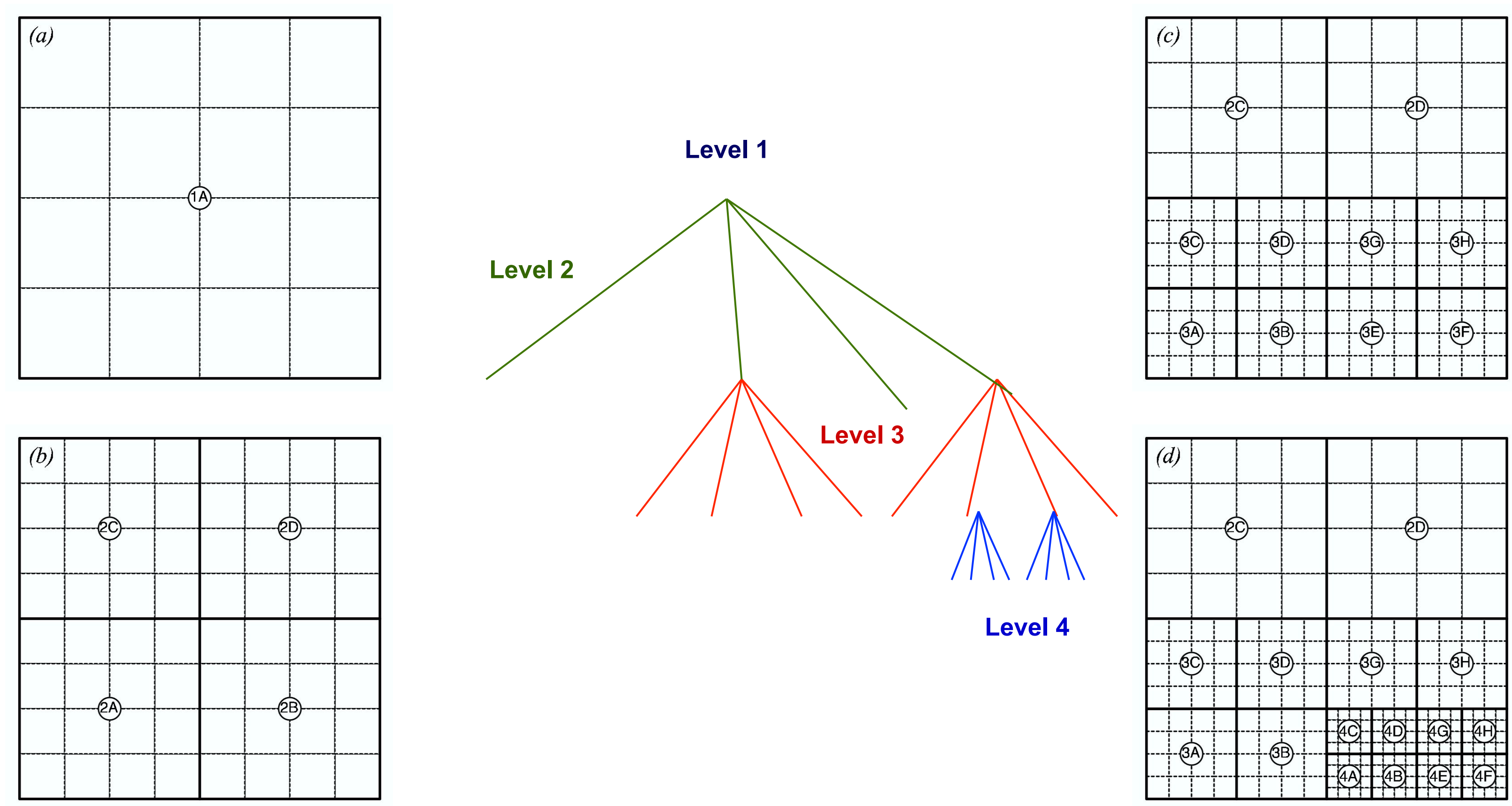
- The grid is composed of blocks
- Cover different fraction of the physical domain.
- In AMR blocks at different levels of refinement have different grid spacing.



# Oct-tree AMR 2D Block Map




- All blocks have same dimensions
- Global block numbers based on Morton order (space filling behavior)
- Blocks have parent-child relation

# AMR: Characteristics

- Useful in applications where different sections of the domain have different characteristics
  - Smooth flow -> low resolution – lower level leaf block
  - Shocks or other structures -> high resolution – higher level leaf block
- The mesh changes dynamically
  - A block may refine – generate 2^d children blocks
  - Blocks may derefine – children blocks go out of existence and their parent becomes the new leaf block
- Applications may choose to evolve on all blocks or only the leaf blocks
  - The union of leaf blocks covers the entire domain
  - When there is no subcycling evolution on parents is not necessary

# AMR: Machinery

Interpolation needed at various points

- Ghost cell filling at fine-coarse boundaries
  - One coarse cell corresponds to two fine cells along each dimension
  - All nearest neighbors of a block are known locally
  - The parent-child relationships for all blocks on a processor are also known locally
- Refinement step
  - Maps and utilities exist for
    - restriction (from higher to lower resolution) from child to parent
    - prolongation (from lower to higher resolution) from parent to child

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# The Data Fidelity

Assertion : For every child block there is a parent block that either does, or if not, can be made to hold lower fidelity data for the same computation that the child block is doing

- In patch based meshes the lower fidelity data is already there because solution evolves on all patches
- In octree meshes, where it is optional to evolve on parents two options exist –
  - force evolution on parent blocks
    - amounts to extra 12.5% work in 3D, 25% in 2D and 50% in 1D
  - restrict to the parent blocks at the end of every time step or operator computation
    - less expensive computationally, more expensive communication wise, but definitely more accurate than evolution

# The Algorithm

- We opt for the restriction option, which could be applied after every expensive physics operator
  - For this work we restricted at the end of every time-step

```
restrict_by_one_level // populate parents
get_list_of_blocks(leaf)
forall blocks
  apply operator_1
  .
  .
  apply operator_2
endfor
if(any_block_had_error)
   prolong_from_parents
   forall faulty blocks
     apply operator_1
     .
     .
     apply operator_2
endif
```

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# Testing

- We did not focus on fault injection and detection
  - the implementations for them are very simplistic
    - read in a range of blocks and a range of time steps in which to introduce faults, and then randomly pick
    - introduce a fault tag in the block metadata
- More interested in being able to control where to introduce faults when
  - to see whether there are faults that are more critical than others in our applications
    - whether the region of the faults matters more or the timing
    - also whether several faults bunched together had greater impact

# Selected Problems

- Isentropic Vortex
  - Smooth flow field with no shocks
  - Vortex at a specified location
  - Faulty blocks placed at the vortex, near the vortex and away from the vortex
- Sod Shock Tube
  - 1D shock discontinuity problem, has multidimensional effects when the shock is placed at an angle
  - Faulty blocks placed very near the shock, in the rarefaction and compression waves and away from the shock

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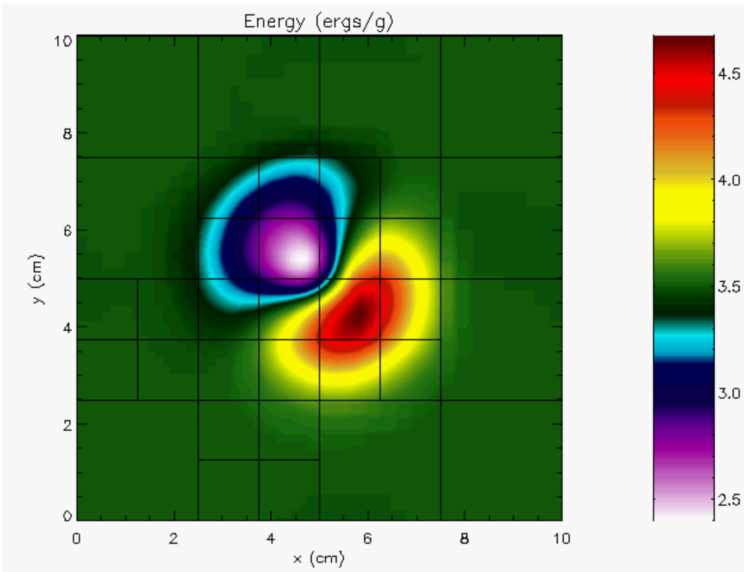
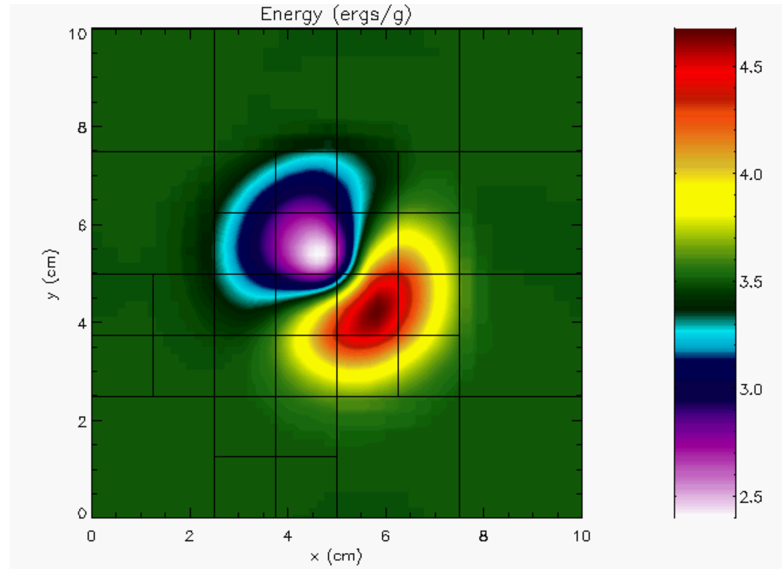
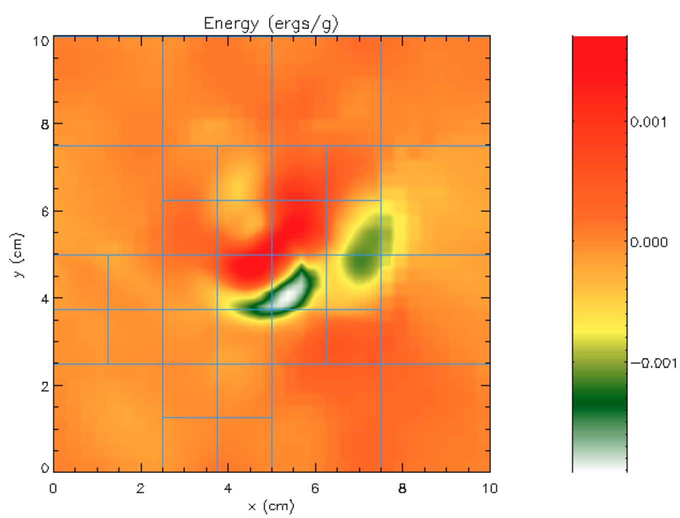
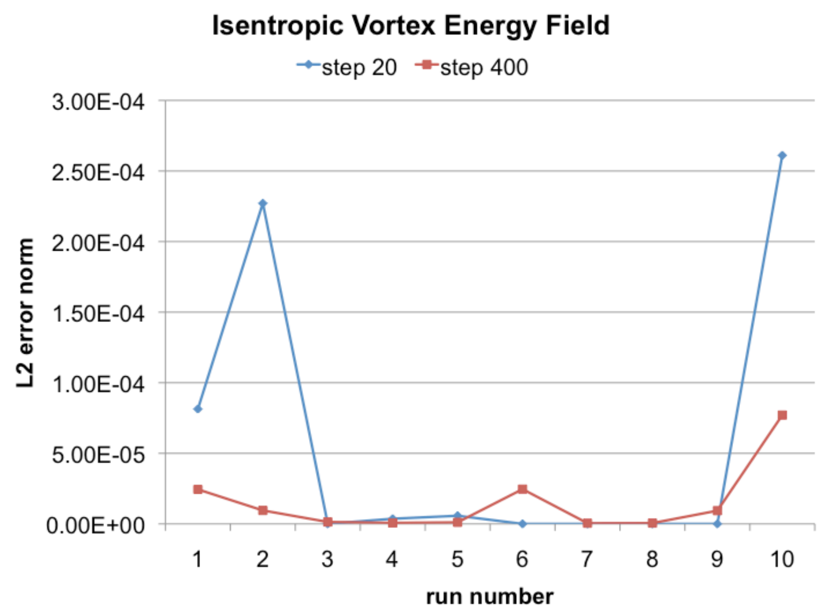
# Isentropic Vortex Results

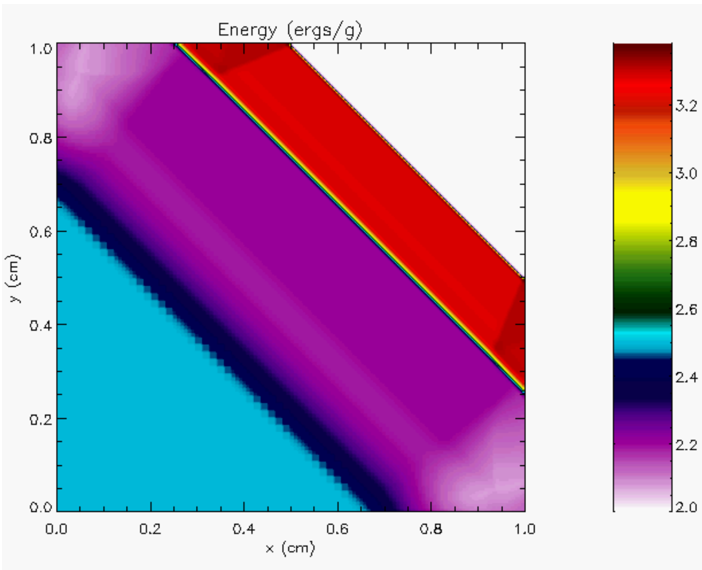


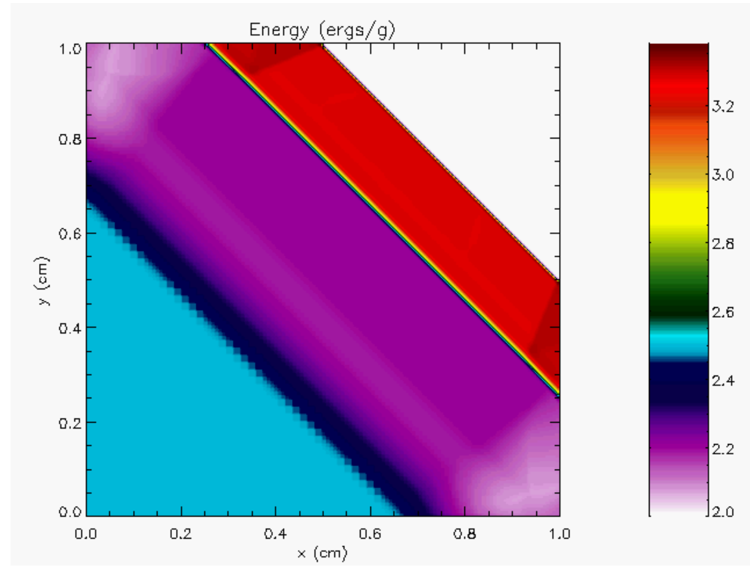



# Sod Results


Energy (ergs/g)
y (cm)
x (cm)


Energy (ergs/g)
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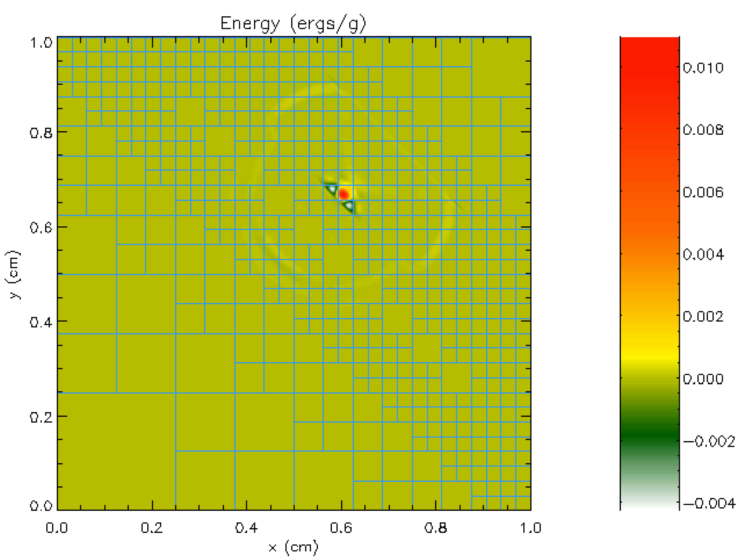
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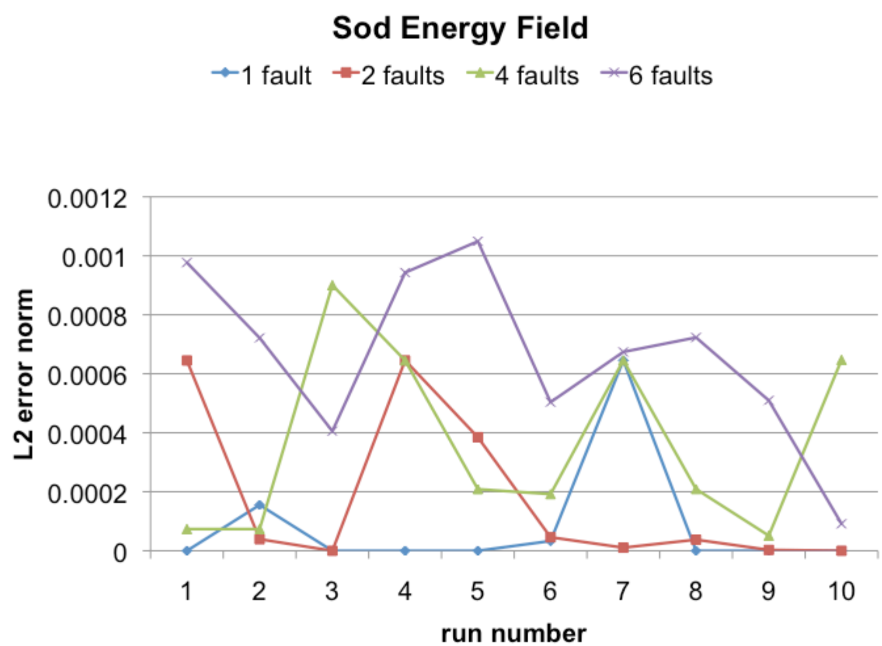
Sod Energy Field
1 fault
2 faults
4 faults
6 faults
L2 error norm
run number

# Findings

- Completely unexpectedly, the problem with shock proved to have robust recovery, even when the fault was placed right at the shock
- In isentropic vortex the impact was higher soon after the fault occurred, but smoothed out later
  - Implication is that it is within the order of accuracy of the numerics
- The impact is not clearly correlated with the placement of fault, but also with count
  - Though it is possible that the higher count implies greater possibility that one of the faulty block is in the more critical region

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# Future Work

- The approach proved to be far more robust than expected
- We have to explore the mathematical arguments for the robustness of the recovery mechanism
- Work on fault injection and detection methods
- Look at rearranging space filling curves and block/ patch distribution
  - Make sure that parent and child blocks are not on the same node
  - Quantify the trade-off in computation cost for resiliency