Visualization and Analysis of Adaptive Mesh Refinement Data

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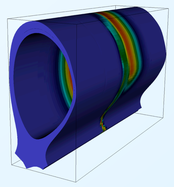
SDAV Support for FASTMath Institute

- SDAV primary source of technology for AMR visual data analysis within FASTMath
- New work this year:
  - Application of VisIt to light intensity modeling for urban energy optimization
  - Visualization of 4D Chombo simulations
  - Assessing future needs: scaling to large number of boxes, EB reconstruction for complex geometry, mapped multiblock data

Visualization of 4D Chombo Simulations

Problem:

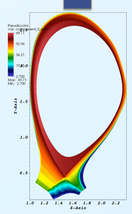
- Increasing number of simulations operate in 4D/5D/6D phase space (position and momentum dimensions), e.g., in fusion
- There are currently no visualization techniques and tools to display and analyze these data sets



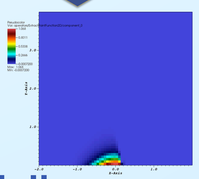
Projection to 3D space:
- *x-/y-axis = position*
- *z-axis = x-momentum*

Approach:

- Develop new visualization methods for high-dimensional data:
  - Multiple coordinated views/brushing & linking
  - Projection to 2D/3D, e.g., via derived fields
    - + Physical quantities (e.g., (bulk/random velocity, temperature, …
    - + Similarity to given distribution function (e.g., Maxwell–Boltzmann distribution)
  - Glyphs



Projection to 2D position space (sum over velocity dimensions)



Velocity distribution at a given spatial location (2D slice in 4D space)

Current Work:

- Enable VisIt to read 4D files (flat, no AMR)
- Prototype implementation of projection to 2D/3D via summation, brushing and linking

Results and Impact:

- Enable scientists to visualize and analyze high-dimensional simulations.

Urban Light Intensity Modeling

Problem:

- Optimize energy consumption of urban area over time
- Calculate light intensity derived from time-series of opacity, direction
- To be used for high-resolution (space, time) solar radiation calculation

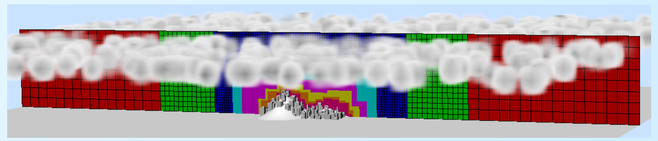
Overall Approach:

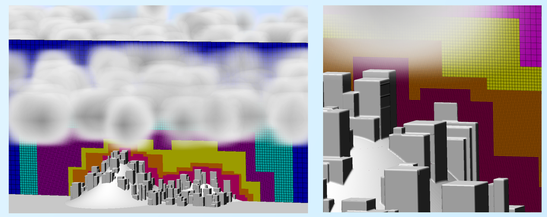
- Combine a CFD simulation of moving “clouds” over complex geometry
- Light angle, building shadows, opaque cloud layer all interact
- Use visual data analysis (VisIt) to compute light intensity transfer through clouds and map it to individual buildings
- Use results as part of time series model for building energy simulation

Current Work:

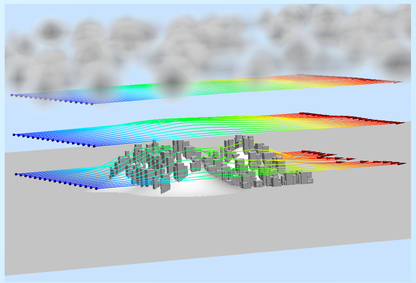
- End-to-end “proof of concept” implementation of all parts of pipleline
  - Chombo urban region example model
  - VisIt for computing light intensity transfer based on direction
  - Building-level total light intensity as time series

Testbed Urban Model (aka “Terryville”)



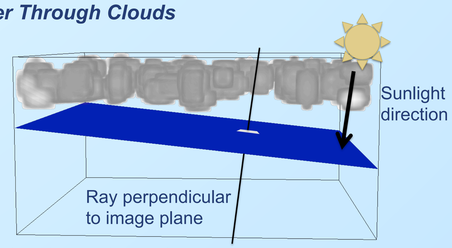


- 64 km^2 X 1 km tall (within reach of global / regional weather prediction)
- Finest domain resolution is 1m^3 – equivalent of 70B points without AMR
- 200M points with AMR (8 levels, 2:1 refinement between levels) – 300x reduction, computed on a 64 core cluster
- Chombo CFD simulation



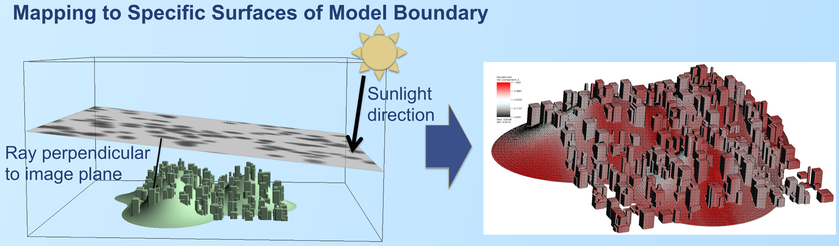
Computing Light Intensity

Light Transfer Through Clouds



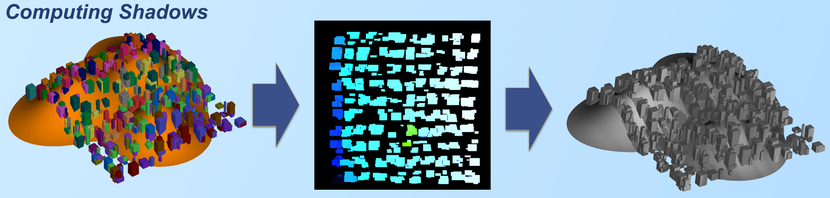
- Map cloud density to absorption rate
- Utilize VisIt’s X-ray query to compute integrated absorption
  - Image plane between clouds and city model, perpendicular to light direction
  - Trace rays perpendicular to image plane (parallel to light direction) and accumulate absorption

Mapping to Specific Surfaces of Model Boundary



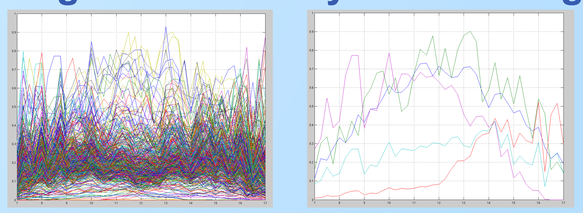
- Reconstruct embedded boundary from cut cells
- For each location, compute intersection of ray parallel to sunlight direction with image plane computed previously (VisIt expressions) and perform look-up in image
- Export for further processing in building simulation

Computing Shadows



- Buildings have unique ID ➔ Encode in 24 bit color value
- Render image from view points of light source with pixels encoding visible building ID (combination of shadow map and OpenGL selection buffer)
- Map visible building ID to each location (analogous to light intensity through clouds)
- Compare with local building ID to determine whether building is in shadow

Computing Total Intensity Per Building



- Utilize intensity/shadow information in second simulation: energy transfer into buildings
- Compute time curves for energy transfer into individual buildings

Future Work

FASTMath

- Visualization and analysis of 4D/6D phase space:
  - Derive meaningful physical quantities (bulk/random velocity, temperature, …)
  - Similarity to given distribution function (e.g., Maxwell–Boltzmann distribution)
- Scaling to large number of boxes
- Embedded boundary reconstruction for very complex geometry
- VisIt support for mapped multiblock data

Urban Light Intensity Modeling

- Use statistically accurate “day ahead” real regional weather models
- Physically accurate solar energy transfer through clouds to surfaces
- Import actual urban region geometry from Google Earth or similar