Visualizing Electromagnetic Field and Particle Simulations in Accelerators with ParaView

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Overview

• Visualization challenges at SLAC
• Using ParaView at SLAC
• Future plans
Special Accelerator Considerations

• We need a high degree of accuracy
  – 2nd order tetrahedral mesh
  – Up to 6th order fields
• Our simulations have huge dynamic range.
  – Field values span tens of orders of magnitude
  – We care about very big and very small values.
• Our meshes can be large (e.g., 17 million elements for a medium sized problem).
How Have We Used ParaView?

- Visualizing our particles and fields (e.g., Multipacting, PIC)
- Parallel rendering for exploration and movie making.
- Fine tuning meshes before simulation.
- With Ken Moreland at Sandia, we have started a simple toolbar to streamline accelerator visualization workflow.
  - Automatic pipeline construction for mesh, particles, and e and b fields.
  - Heuristic for automatic normalization of fields from wakefield simulations.
ParaView Generated Movies

- Multipacting
- Wakefield
- Power flow
- 3D Stereo
Multipacting Movie

- **What is multipacting?**
  - Resonant trajectories
  - Enhancement

- **Why is multipacting important?**
  - Can cause damage to accelerator structure
  - Limits operating power of structure

- **Movie Information**
  - Meshing and Simulation: Lixin Ge at SLAC
  - Saturated color: particle momentum (energy)
  - White trails: recent particle trajectory
  - Desaturated color: electric field magnitude
  - Wireframe: view dependent mesh exterior
  - Surface: view dependent mesh interior
Multipacting Simulation (context)
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Multipacting Simulation

Multipacting in an SNS Cavity HOM Coupler

Rendered in parallel, on a 4 processor Sun Ultra 40
Wakefield Movie

• What is a wakefield?
  – Electromagnetic fields behind a particle bunch
  – Analogies:
    • Waves from a boat on a smooth lake
    • Turbulence left behind an aircraft

• Why are wakefields important?
  – Can cause harmful surface heating
  – Can kick bunch particles sideways, off path

• Movie Information:
  – Context: CLIC PETS
  – Meshing and Simulation: Arno Candel at SLAC
  – CAD Model: CERN
  – Field scaling is: \( \sqrt{\text{mag}(\text{efield})} \)
Field Scaling Functions
time: 00.000 ns
Power Flow Movie

- **What is power flow in this movie?**
  - One accelerator is used to power another.
  - Power flow shows where the resonant fields build up for particle acceleration.

- **Why is power flow important?**
  - Analogy: buildup of large waves for surfing
  - Is the (very complicated) structure operating as intended?

- **Movie Information:**
  - Context: CLIC structures
  - Meshing and Simulation: Arno Candel at SLAC
  - 17 million quadratic elements
  - CAD Model: CERN
  - Field scaling is linear power: \( (\text{efield.efield} + \text{bfield.bfield}) \)
  - Filling takes a very long time, so this movie is highly accelerated.
time: 00.0 ns
3D Stereo Movie

• What is 3D Stereo?
  – Left eye and right eye see slightly different images.
  – Appears truly 3D, not just perspective projection of 3D onto 2D.

• Why is 3D Stereo important?
  – Provides more accurate sense of true 3D structure.
  – Effectively shows depth relationships.
  – Useful for very complex structures (accelerator structure, particle paths)

• Movie Information:
  – Same as previous movie.
  – **Left Eye Only**! Please see true stereo at the SLAC National Accelerator Center exhibit (Booth 901).
Power Flow in the CLIC Two-Beam Accelerator
Our Plans for ParaView

• Support for massively parallel visualization
  – Compile and make available on
    • DaVinci at NERSC
    • Lens at ORNL
• SBIR Phase II with Kitware
  – Collaborative Visualization
  – Higher order fields (up to 6th order)
  – Higher order geometry (2nd order)
  – Interactor for structures with high aspect ratio
• Possible SBIR Phase II with Kitware
  – Comparative visualization
Thank you.