Flow Visualization Research @ IDAV

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CScADS Workshop on Scientific Data Analysis and Visualization for Petascale Computing
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Flow Illustration with Integral Surfaces

(with Hari Krishnan, Ken Joy)
Integration-Based Flow Vis

Integral Curve

Intuitive interpretation: path of a massless particle
Computation in datasets: numerical integration
Integral Surfaces

- Generalization: path surfaces

- Interpretation: surface spanned by a family of integral curves, originating from a common curve
Integral Surfaces

Flow over a car, 38M unstructured cells

seeding curve
Integral Surfaces

• Step 1: Compute initial approximation, points on $t_1$ are advected from $t_0$
Integral Surfaces

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• Step 2: Apply refinement predicate on adjacent point triples to determine where better resolution is needed.
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- Step 3:
  Insert new points
Integral Surfaces

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- Repeat at Steps 2 and 3 until no further refinement is needed
Integral Surfaces

- Approximate sequence of timelines going from $t_i$ to $t_{i+1}$
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- Result: Surface skeleton of integral curves + time lines
• Use adjacent integral curves and triangulate heuristically with shortest diagonals.
Phase 2: Surface Triangulation

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Integral Surfaces

Proposed method: (Vis 08)

- adaptive approximation
  - integral curve divergence/convergence
  - surface deformation (folding, shearing)

- temporal locality
  - allows streaming of large time-varying vector fields

- spatial locality
  - only considers neighboring curves, allows parallization
Integral Surfaces
Visualization / Rendering options

- Transparent
- Transparent with color
- Ambient occlusion

Turbulent CFD simulation, 200M unstructured cells
Integral Surfaces

Flow past an ellipsoid, 2.6M unstructured cells x 1000 timesteps

Vortex formation behind an ellipsoidal body
Integral Surfaces

Flow over a delta wing, 18M unstructured cells x 500 timesteps
Integral Surfaces

Ongoing work (Vis 09):

Time Surfaces (seed surface)
Streak Surfaces (continuous seeding from a curve)
Integral Surfaces
Integral Surfaces
Integral Surfaces

Performance:
- require 100 - 100,000 pathlines, depending on complexity of data and surface
- computation times (1 CPU) can range up to hours for very complex surfaces
- time spent integrating pathlines > 90%
- parallelization is in the works

We provide tools for interactive viewing, spatial + temporal navigation
Lagrangian Flow Visualization
(with Xavier Tricoche, Mario Hlawitschka, Ken Joy)
Lagrangian Flow Visualization

- Lagrangian Flow Vis - look at what particles do
- Finite-Time Lyapunov Exponent
- Measures exponential separation rate between neighboring particles
- Identifies Lagrangian Coherent Structures
Lagrangian Flow Visualization

- Computation: dense particles + derivatives

- Interpretation of FTLE:
  - separation forward in time: indicates divergence
  - separation backward in time: indicates convergence
Lagrangian Flow Visualization

Time-dependent vs. time-independent FTLE fields
Lagrangian Flow Visualization

3D Visualization: DVR of FTLE fields using a 2D transfer function

Computation is extensive, but we use GPUs for small data, and adaptive computation for medium-sized data.
Lagrangian Flow Visualization

Often effective visualizations with relatively little application knowledge.

Wish list:

• feature identification
• feature tracking
Lagrangian Flow Visualization

Visualization tool:
section plane FTLE +
user interaction

Pathlines seeded
according user brushing

Delta Wing

Section plane orthogonal to main flow direction
Lagrangian Flow Visualization

• Application to DT-MRI / tensor data
• Interest in coherent fiber bundles / bundle separation

joint work with X. Tricoche (Purdue), M. Hlawitschka
Lagrangian Flow Visualization

- Hamiltonian Systems (Fusion, Astrophysics, ...)
- Coherent Structures: Island Chain Boundaries

Standard Map
Tokamak Simulation
$10^6$–$10^9$ integral curves
Improved Integration

(with Dave Pugmire, Sean Ahern, Hank Childs, Gunther Weber, Eduard Deines)
Improved Integration

• Integrating many curves is a hard problem
  – non-linear
  – data-dependent
  – requires fast interpolation in arbitrary meshes

• Strong need for parallelization
  – large data (petascale)
  – large seed set (millions of integral curves)
  – correct handling difficult mesh types (e.g. AMR)
Improved Integration

• Wish list for improved integration:
  – parallelize over both data and seed point set
  – avoid bad performance in corner cases
    • large data, small seed set
    • small data, large seed set
    • precludes any kind of static partitioning
  – handle data in existing format, no repartitioning or expensive up-front analysis, general use case

• Ongoing work: adaptive load balancing using a master-slave approach and distribution heuristics (SC09 paper: comparison of different approaches)
Improved Integration

Ongoing: Correct handling of AMR meshes

- Problem 1: cell-centered data
  - need good interpolation scheme
  - cell-node averaging is **not** the right thing
    (too much smoothing)
  - dual mesh interpolation behaves much better
Correct handling of AMR meshes:

- Problem 2: discontinuities across AMR resolution boundaries
  - adaptive integration cannot handle this smoothly, or fails outright
  - “stopping” integration across boundary results in decreased numerical error

Integration should work out-of-the-box, without a user worrying about the details.
Improved Integration

ignored discontinuities + averaging

explicit disc. handling + dual mesh
• Where can I download this?
  – Nowhere, yet :-(

• Integration into Visit is underway
  – Improved integration in Visit very soon
  – Integral Surfaces + FTLE visualization are being incorporated
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Questions?