Flow Visualization by Texture Advection

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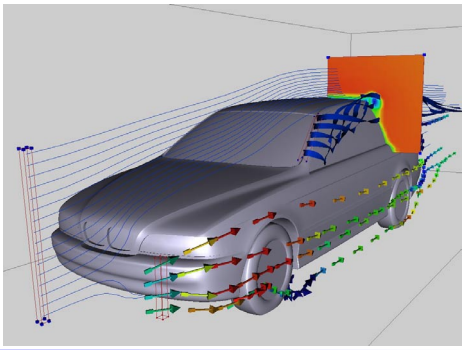
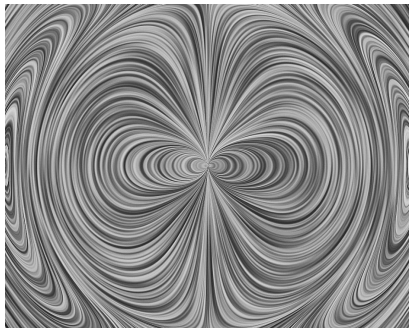
Introduction

- Vector field visualization: indirectly by tracing particles
- Issues:
  - Seed point positioning
  - Dense vs. sparse representation
  - Steady vs. unsteady flow fields
  - Visualization speed

Introduction



Introduction



Related Work

- Mapping/rendering techniques:
  - Streamlines, streaklines, ribbons, etc.
  - Spot noise [Wijk 91]
  - Texture splats [Crawfis & Max 93]
  - LIC [Cabral & Leedom 93, Stalling & Hege 95], etc.
  - Texture advection [Max et al. 92/96]
  - Lagrangian-Eulerian Advection [Jobard et al. 01]
  - Image-Based Flow Visualization [van Wijk 02]

Related Work

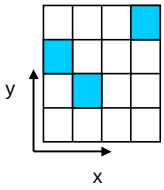
- Hardware-based:
  - LIC [Heidrich et al. 99]
  - Texture advection [Jobard et al. 00]
  - Lagrangian-Eulerian Advection [Weiskopf et al. 02]
  - Image-Based Flow Visualization [van Wijk 02]

Lagrangian Approach

- Velocity vector **v**
- Trace massless particles
- Particles identified individually
- Attached are position **r**, velocity **v**, and other properties (color etc.)
- Equation of motion: $\frac{d\mathbf{r}}{dt} = \mathbf{v}(\mathbf{r},t)$
- First order integration: $\Delta\mathbf{r} = \Delta t \cdot \mathbf{v}(\mathbf{r},t)$

Eulerian Approach

- Properties given on a grid, not with respect to particles
- Position is implicit
- Sampling of particles on regular grid (= texture)



Dye Advection

- Inject color dye (ink)
- Dye is advected along the flow

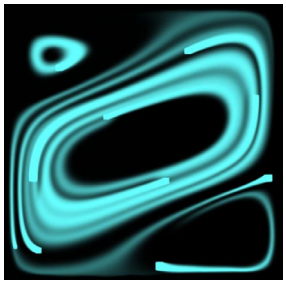
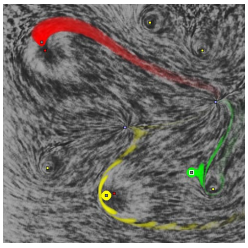
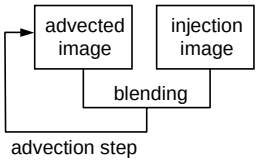


Image-Based Flow Visualization

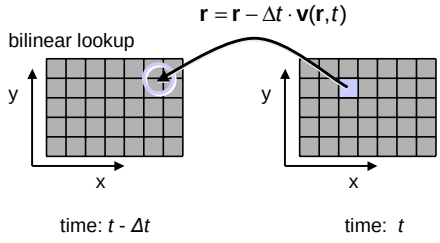
- Basic idea:
  - Advection of particle field
  - Blending of particle injection texture (at each time step)





[generated by van Wijk's demo program]

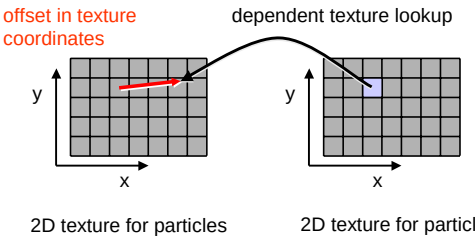
Basic Texture Advection



Basic Texture Advection

- Forward mapping could produce gaps
- Backward mapping avoids gaps
- Bilinear interpolation:
  - Artificial diffusion
  - Caused by "averaging" via interpolation
  - For dye advection
  - For IBFV

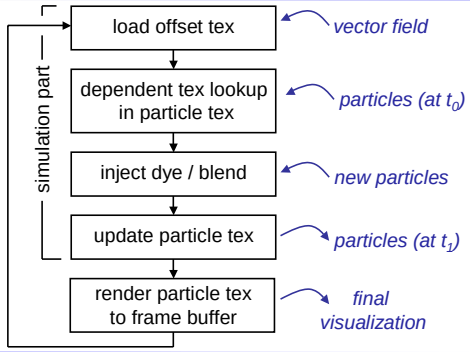
Advection in Hardware



Advection in Hardware

- Representation:
  - Particles by standard 2D RGB texture
  - Vector field by 2D signed texture, with 2 components
  - Computational domain by rendering a rectangle ⇒ generates fragments

Advection in Hardware



Advection in Hardware

- Pixel Shader 1.0 code:

```
tex t0
texbem t1,t0
mov r0, t1
```

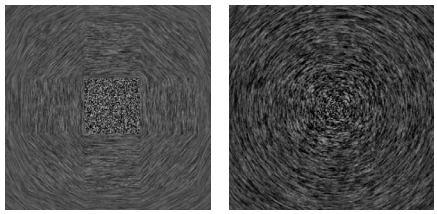
- Runs on PS 1.0 class GPUs (e.g. GeForce 3 or Radeon 8500)

Lagrangian-Eulerian Approach

- Combination of Eulerian and Lagrangian approaches
- Lagrangian-Eulerian Advection (LEA)
- Split in two parts:
  - Lagrangian: Update of coordinates of particles (*coordinate integration*)
  - Eulerian: Particle properties attached to grid (*property advection*)

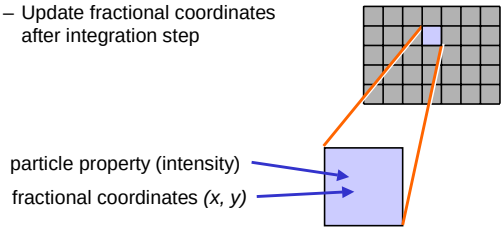
Lagrangian-Eulerian Advection

- Replace bilinear interpolation by nearest neighbor lookup
- Problem: Particles may stay in respective cell for small velocity or step size



Lagrangian-Eulerian Advection

- Solution:
  - Store fractional coordinates in texture
  - Take fractional coordinates into account during integration
  - Update fractional coordinates after integration step



LEA in Hardware

- Similar to hardware-based bilinear advection
- Fractional coordinates
- Nearest-neighbor sampling
- Requires functionality of Radeon 8500
- DirectX with Pixel Shader 1.4 or 2.0

LEA in Hardware

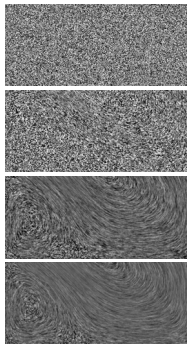
- Use RGBA texture to store
  - Property (intensity) of particle
  - 2 fractional coordinates
  - [Blended property texture]
- Single pass rendering:
  - Integrate coordinates
  - Update fractional coordinates
  - Update property (= noise) texture
  - [Blended property texture]

Noise Blending for LEA

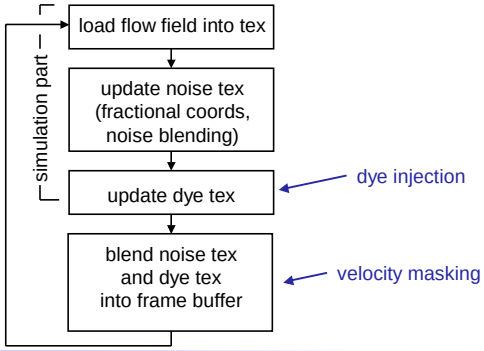
- Blending of two (temporally) subsequent noise images via

$$\mathbf{C} \rightarrow \alpha \mathbf{C}_{\text{new}} + (1-\alpha)\mathbf{C}$$

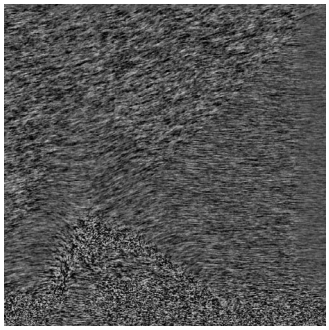
- Introduces spatial coherence from temporal coherence



Complete Visualization Process

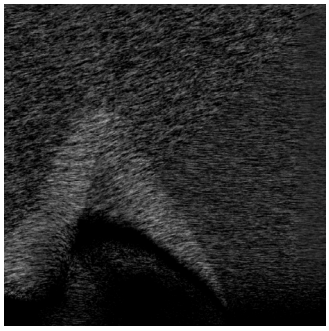


LEA Results



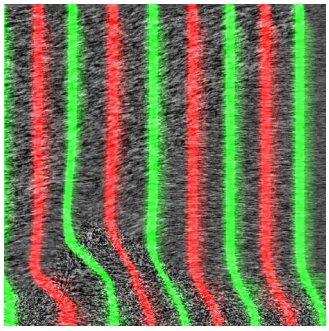
- Noise advection
- Interaction of a planar shock with a longitudinal vortex

LEA Results



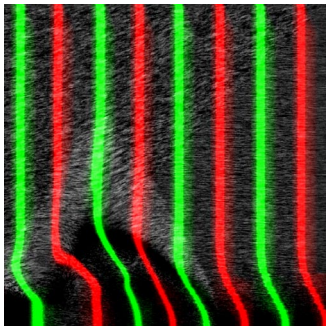
- Noise advection
- Velocity masking
- Interaction of a planar shock with a longitudinal vortex

LEA Results



- Noise advection
- Dye advection
- Interaction of a planar shock with a longitudinal vortex

LEA Results



- Noise advection
- Dye advection
- Velocity masking
- Interaction of a planar shock with a longitudinal vortex

Further Reading

- Dye advection on GeForce 3 [Weiskopf et al. 01]
- LEA on Radeon 8500 [Weiskopf et al. 02]
- Image-Based Flow Visualization [van Wijk 02]

References

[Cabral & Leedom 93] B. Cabral, L. C. Leedom. Imaging vector fields using line integral convolution. In *SIGGRAPH 1993 Conference Proceedings*, pages 263-272.

[Crawfis & Max 93] R. Crawfis, N. Max. Texture splats for 3D scalar and vector field visualization. In *IEEE Visualization '93*, pages 261-267.

[Heidrich et al. 99] W. Heidrich, R. Westermann, H.-P. Seidel, T. Ertl. Application of pixel textures in visualization and realistic image synthesis. In *ACM Symposium on Interactive 3D Graphics*, pages 127-134,1999.

[Helman & Hesselink 89] J. Helman, L. Hesselink. Representation and display of vector field topology in fluid flow data sets. *IEEE Computer*, 22(8), pages 27-36, August 1989.

[Jobard et al. 00] B. Jobard, G. Erlebacher, M. Y. Hussaini. Hardware-accelerated texture advection for unsteady flow visualization. In *IEEE Visualization 2000*, pages 155-162.

[Jobard et al. 01] B. Jobard, G. Erlebacher, M. Y. Hussaini. Lagrangian-Eulerian advection for unsteady flow visualization. In *IEEE Visualization 2001*, 53-60.

References

[Max et al. 92] N. Max, R. Crawfis, D. Williams. Visualizing wind velocities by advecting cloud textures. In *IEEE Visualization '92*, pages 171-178.

[Max & Becker 96] N. Max, B. Becker. Flow visualization using moving textures. In *Proc. ICASE/LaRC Symposium on Visualizing Time Varying Data*, D. C. Banks, T. W. Crockett, S. Kathy (eds.), pages 77-87, 1996.

[Stalling & Hege 95] D. Stalling, H.-C. Hege. Fast and resolution independent line integral convolution. In *SIGGRAPH 1995 Conference Proceedings*, pages 249-256.

[Turk & Banks 96] G. Turk. David Banks. Image-guided streamline placement. In *SIGGRAPH 1996 Conference Proceedings*, pages 453-460.

[Verma et al. 00] V. Verma, D. Kao, A. Pang. A flow-guided streamline seeding strategy. In *IEEE Visualization 2000*, pages 163-170.

References

[Weiskopf et al. 01] D. Weiskopf, M. Hopf, T. Ertl. Hardware-accelerated visualization of time-varying 2D and 3D vector fields by texture advection via programmable per-pixel operations. In *VMV '01 Proceedings*, pages 439-446, 2001.

[Weiskopf et al. 02] D. Weiskopf, G. Erlebacher, M. Hopf, T. Ertl. Hardware-accelerated Lagrangian-Eulerian texture advection for 2D flow visualization. In *VMV '02 Proceedings*, pages 77-85, 2002

[van Wijk 91] J. van Wijk. Spot noise-texture synthesis for data visualization. In *SIGGRPAPH 1991 Conference Proceedings*, pages 309-318.

[van Wijk 02] J. van Wijk. Image based flow visualization. *ACM Transactions on Graphics* 21 (3), pages 745-754, 2002.