Detail Preserving Fluid Control

N. Thuerey\textsuperscript{1,2}, R. Keiser\textsuperscript{1}, M. Pauly\textsuperscript{1}, U. Ruede\textsuperscript{2}

- Applied Geometry Group, ETH Zurich, Switzerland
- Department for System Simulation, University of Erlangen-Nuremberg, Germany
Overview

• Introduction
• Detail Preserving Control
• Control Particle Generation
• 3D Results
• Conclusions
Fluid Control
Related Work

Among others:

- *Taming Liquids for rapidly changing Targets*, Lin Shi et al, SCA 2005
- *Fluid Control using the Adjoint Method*, McNamara et al, SIGGRAPH 2004
- *Directable photorealistic Liquids*, Rasmussen et al, SCA 2004
A Particle Based Control Framework

- Control Particles with Influence Radius
- Apply Attraction/Velocity Forces
- Intuitive for Animators
- Wide Range of Generators for Particles
A Particle Based Control Framework

Motion given by math. Function or Keyframes
Shape given by an arbitrary Mesh
Motion and Shape from another Fluid Simulation with advected Tracers

Generated Control Particles with Influence Radius and Motion
Attraction Forces
Velocity Forces
Evaluate Forces for Fluid Elements

SCA ‘06: Detail Preserving Fluid Control
Thuerey, Keiser, Pauly, Ruede
Free Surface Fluids

• Lattice Boltzmann Method:
  – Grid Based
  – VOF Free Surface Model

• Smoothed Particle Hydrodynamics
  – Particle Based
  – Inherent Free Surface Treatment
Some Comments regarding Fluid Solvers

- LBM + VOF: Efficiency, Mass Conservation, Small Time Steps, Memory Requirements
- SPH: No Grid, Particles, Compressibility, Smoothing
- Level-Set + semi-Lagrangian. Solver: Smooth Surface, Large Time Steps, Auxiliary Particles, Global Correction
- More Alternatives: Dynamic Meshes (e.g. Klingner/Chentanez et al), PIC/FLIP (e.g. Zhu&Bridson), Simplicial Fluids (Elcott et al), and other variants...
Overview

• Introduction
• **Detail Preserving Control**
• Control Particle Generation
• 3D Results
• Conclusions
Detail Preservation

3D Fluid Simulation, flow to the right with vortices

Control Force Field generated from Control Particles
Detail Preservation

3D Fluid Simulation, flow to the right with vortices

Control Force Field generated from Control Particles

Fluid Velocities

Control Velocities
Detail Preservation
Detail Preservation

SCA ‘06: Detail Preserving Fluid Control
Thuerey, Keiser, Pauly, Ruede
Detail Preservation

Apply Control (weight=0.5)

Velocities after direct Control

Apply High- and Low-Pass Filter

Fluid Velocities

Control Velocities
Detail Preservation

SCA '06: Detail Preserving Fluid Control
Thuerey, Keiser, Pauly, Ruede
Detail Preservation

SCA ‘06: Detail Preserving Fluid Control
Thuerey, Keiser, Pauly, Ruede
Detail Preservation

Evaluation of Control Forces:

\[ f_a = w_a \sum_i \alpha_i \ d \ W(l) \]

\[ f_v = w_v \sum_i [v_i - v(e)] \ W(l) \]
Detail Preservation:

\[ \mathbf{v}(e) = \frac{\sum_i \tilde{\mathbf{v}}_i W(l)}{\sum_i W(l)} \]

\[ \tilde{\mathbf{v}}_i = \frac{\sum_e \mathbf{u}(e) W(l)}{\sum_e W(l)} \]

Computation of the Fluid Velocity Field filtered with the Control Particle Influence Kernels

Interpolation of the filtered Velocities to obtain the smoothed Velocity Field

Performance Cost for Evaluation: 2-4%
Detail Preservation - 3D Example
3D Example - Direct Control

Zur Anzeige wird der QuickTime Dekompressor YUV420 oder 
Scalpel.
3D Example - Detail Preserving Control
3D Example - Direct Comparison
Overview

- Introduction
- Detail Preserving Control
- Control Particle Generation
- 3D Results
- Conclusions
CP Generation 1 - Math. Function

CP Generation 2 - Shape Matching

- E.g. Animation of a Fluid Character
- Sample Points in a Triangle-Mesh
- Transfer Motion using Mean Value Mesh Coordinates (see Tao Ju et al, SIGGRAPH 2005)
CP Generation 2
Shape Matching Example - Horse

Zur Anzeige wird der QuickTime Dekompressor YUV420 codec benötigt.
CP Generation 3 - Fluids

• Use Fluid Simulations to control Fluids
• Trace Markers in Fluid Velocity Field
• Use as Control Particles
• Modifications: e.g. Reverse Motion, modified Time Scale
CP Generation 3 - Fluids
Example: Flowing up Stairs

• Normal Simulation:
CP Generation 3 - Fluids
Example: Flowing up Stairs

• Negative Example, reversed Playback:
CP Generation 3 - Fluids

Example: Flowing up Stairs

• Direct Control:

Zur Anzeige wird der QuickTime Dekompressor YUV420 mit der Quelldatei.
CP Generation 3 - Fluids
Example: Flowing up Stairs

• Detail Preserving Control:

Zur Anzeige wird der QuickTime Dekompressor YUV420 nicht benötigt.
Overview

• Introduction
• Detail Preserving Control
• Control Particle Generation
• 3D Results
• Conclusions
Terminator Sequence

Zur Anzeige wird der QuickTime DeKompressor benötigt.
Magician - Duck Fight
Overview

• Introduction
• Detail Preserving Control
• Control Particle Generation
• 3D Results
• Conclusions
Conclusions

• Powerful & Flexible Control Framework based on Particles
• Detail Preservation: coarse large scale Control with natural Motion possible
Outlook

- Anisotropic Kernels
- Sketch Based Control Particle Generation
- Alternative Scale Separation Techniques

Acknowledgements: M. Carlson, D. Epps, M. Gross, M. Stamminger

Thanks for your attention!