Fluid Simulation Interaction Techniques (Sketches 0240)

Magnus Wrenninge *
Norrköping Visualization and Interaction Studio
Linköping University, Sweden

Doug Roble †
Digital Domain

1 Introduction

Level set surfaces are well suited for representing the complex surface of a liquid in a fluid simulation. At Digital Domain we have developed a fluid simulation package that represents all objects, not just the liquid, as particle corrected level sets and velocity fields. This framework enables easy experimentation with all aspects of the simulation, including adding new ways of interacting with the liquid.

This presentation will illustrate the power of the framework with the following new concepts: moving, deforming objects represented as level sets; level set sources and drains; a generalized way of manipulating the velocity field, based on an image compositing paradigm.

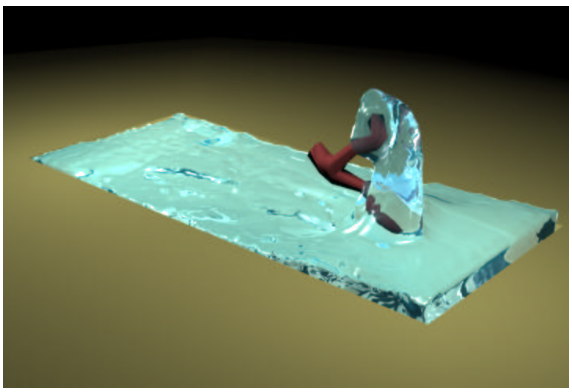

Figure 1: Moving, deforming object, represented as a level set, interacting with a liquid.

2 Moving, Deforming Objects

In [Foster and Fedkiw 2001], the authors describe using level sets to represent the liquid and a voxelized representation for static objects in a fluid simulation. However, they leave moving objects in their polygonal representation. We implemented a very similar system, but could not resist the temptation to represent all objects as level sets. There are many benefits to a level set representation, the gradient/normal at any point is easy to compute, inside/outside tests are trivial and CSG operations are natural and simple.

There are some challenges to this approach. First, a robust, fast method to convert from a polygonal object to a level set representation is needed. We discuss this method in a separate presentation. Second, for moving, deforming objects, a corresponding vector field is needed to represent the typically non-uniform velocity of each voxel in the object. By using a windowed radial basis function, we are able to interpolate the non-uniformly distributed velocities present at vertices on the surface of the object throughout the voxel space of the object. Finally, in order to satisfy the CFL condition of the fluid simulation, the internal time step is likely much finer than the 30 frames per second object animation. The brute force way to address this problem is to simply ask the animation package to create a sub-frame instance of the geometry and convert that to a level set and velocity field, this produces a large number of files. We have been experimenting with using the velocity field associated with the level set at a frame of the animation to move the level set forward to produce a sub-frame level set.

3 Direct Manipulation of Velocity Fields

When dealing with user interaction, methods of using 3D splines to alter the motion of the liquid have been described. When we looked at what other "motion primitives" might be needed, we found that any number could be conceived, and that a generalized layer separating the engine from specific interaction elements was needed. Our goal was to allow artists to develop custom interaction elements, without having to alter the simulation engine at all. We found that by accepting vector fields as inputs, the simulation could be driven both kinematically and dynamically through velocity and force-fields, respectively. And by adding an alpha channel, the artists could "composite" the many velocity fields together.

4 Sources, Drains and Water Recorders

Sources and drains provide a convenient way of introducing or removing water from the fluid simulation. Level sets represent the shape of the source or drain and velocity fields control how water direction and speed of the water.

This uniform level set / velocity field framework makes integrating moving objects, sources and drains is conceptually simple. Using the trivial CSG operations provided by level sets, the moving objects can be unioned with the static objects and their velocities merged into one velocity field for all objects. Likewise, the source (or drain) level sets can be unioned (or differenced) with the existing liquid in the simulation to produce (or destroy) liquid.

Finally, we have implemented a "water recorder" that combines many of the previous techniques. An arbitrarily shaped area that water will be flowing through is specified. As the simulation progresses, the water and velocities inside this area are written to separate level set and velocity field files. These files can be used as animated sources to run a smaller section of the simulation again or at a higher resolution. These level sets can even be used as a moving, deforming object in another fluid simulation, providing a cheap way to simulate a much lighter liquid flowing over a much heavier liquid.

References

FOSTER, N., AND FEDKIW, R. 2001. Practical animations of liquids. In *SIGGRAPH 2001, Computer Graphics Proceedings*, ACM Press / ACM SIGGRAPH, E. Fiume, Ed., 23–30.

*e-mail: magwr867@student.liu.se
†e-mail: doug@d2.com