Dynamic Feature Guided Fluid Texturing

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The Challenge

Realistic modeling, simulation, and rendering of fluid media have applications in various domains including virtual reality training, engineering visualization, medical simulation, computer animation, and electronic games. Often the computational expense involved in simulating complex fluid phenomena limits the resolution at which these simulations can be performed. This limitation makes it extremely difficult to synthesize complex *fine-resolution phenomena* on the free surface of the fluid, such as small-scale ripples in a river stream, foam and bubbles in turbulent water, patterns in lava flow, etc. Even with a highly robust and sophisticated fluid simulation system capable of modeling such structures, it is quite difficult to control the shape and appearance of these structures within the simulation in a reasonable amount of time.

The Approach

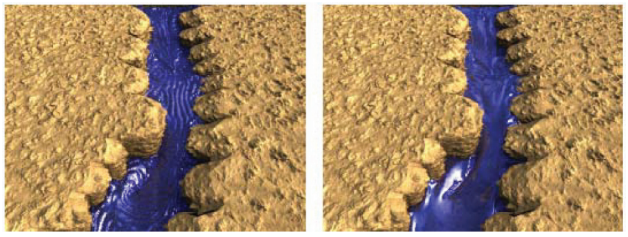
Texture mapping is a common approach for increasing the realism of low-resolution models by adding the appearance of fine surface detail. Recent techniques for texture synthesis allow realistic textures to be generated on static 3D surfaces from input texture examples. Typically, the fine-scale patterns on fluid flows also behave like a texture, *i.e.* the fluid appearance consists of local features that are statistically self-similar over space and time. We explore a new approach to aid and complement the fluid simulation process by using examples or samples of fluid shape and appearance to synthesize a *dynamic flowing texture* on the simulated fluid surface.

To ensure that the generated texture flows along with the fluid over time while also remaining similar to the given input, we use a combination of texture transport and texture synthesis over the fluid surface to obtain our results. At each time step, texture is advected along the velocity field of the fluid obtained from the simulation, and then re-synthesized using our texture optimization algorithm to maintain fidelity to the input texture.

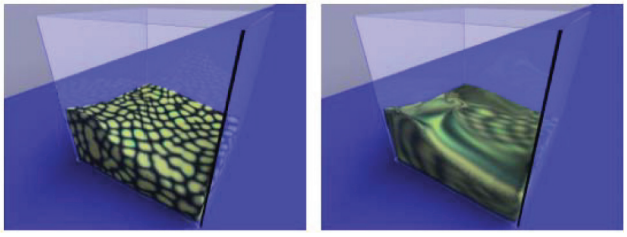
An important observation is that in real fluids, these detailed texture-like phenomena are not uniform over the fluid surface but vary over space and time, and are correlated with the underlying physical characteristics of the flow. It is non-trivial to generate such evolving, *heterogeneous textures* over arbitrary fluid surfaces in a physically consistent and visually convincing manner. We extend our basic fluid texturing algorithm using a novel technique in which the physical and geometric characteristics of the flow are used to intelligently guide the synthesis of *dynamic, non-uniform* textures over its domain. These characteristics, which we term as *features*, are used to

Highlights

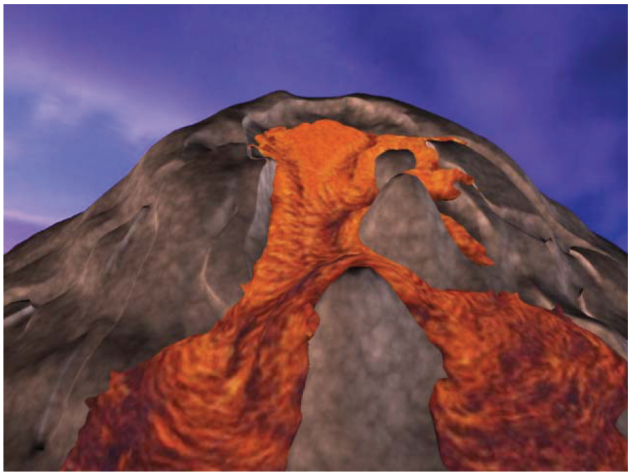
- **Novel algorithm for synthesizing textures on dynamically changing fluid surfaces.**
- **Texture transport along 3D fluid undergoing complex topological changes, while preserving texture quality.**
- **Novel formulation for advection of vector quantities like surface orientation through the velocity field.**
- **Combine physical and geometric features on continuous flows with image and video textures, using an optimization-based texture synthesis framework.**



River rendered with a wave-like displacement texture is shown on the left. On the right, it is rendered without using any texture.

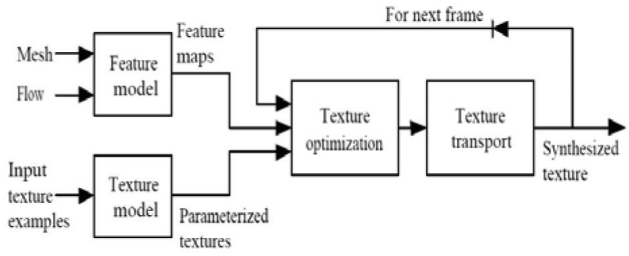


Comparison between using texture synthesis in addition to texture advection (left) vs. using texture advection alone (right).



Lava flowing down a mountain: texture synthesis is guided by the features of lava flow. Here, regions distant from the source are colder and therefore are given a darker texture.

model the behavior of surface flow phenomena over space and time. This model then automatically controls the synthesis of a spatially and temporally varying texture over each frame of the simulation using multiple, dissimilar input textures. Our technique can be used to easily enhance the visual realism of simulated liquid simulations by adding realistic surface detail. Another application of this technique is to automatically manipulate the flow and behavior of pre-recorded video footage of real fluids such as water, fire, and clouds.



An overview of our approach for feature-guided texturing on fluids.

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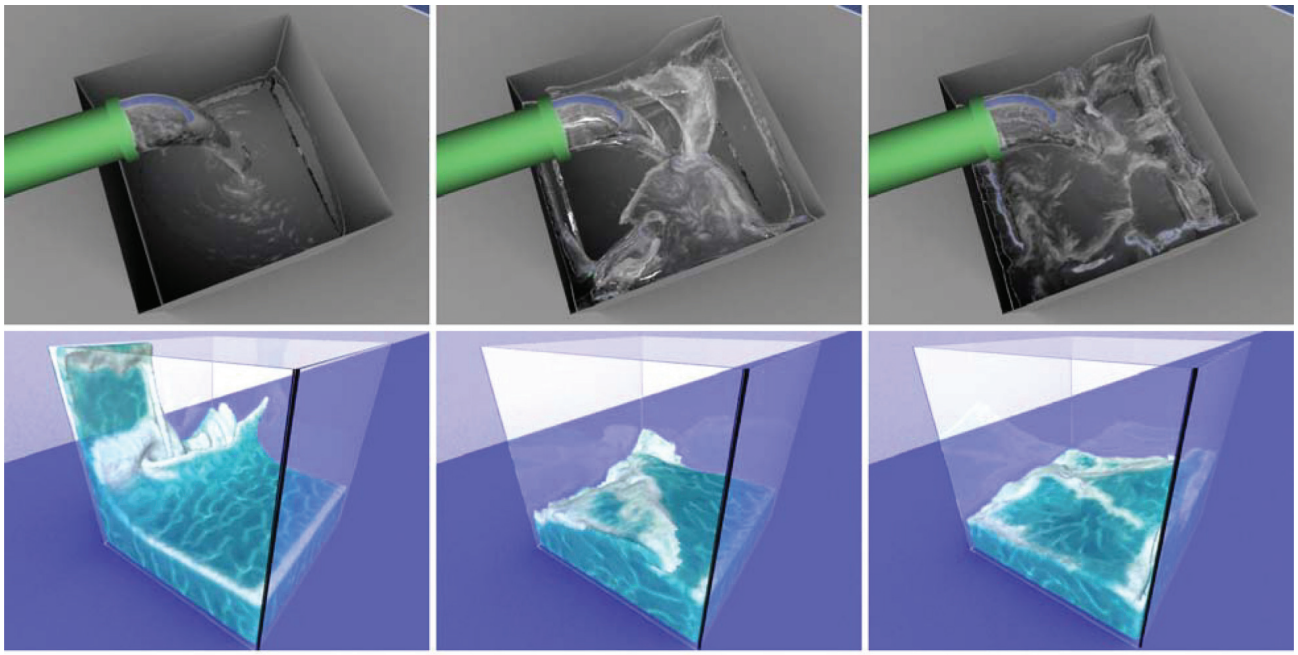
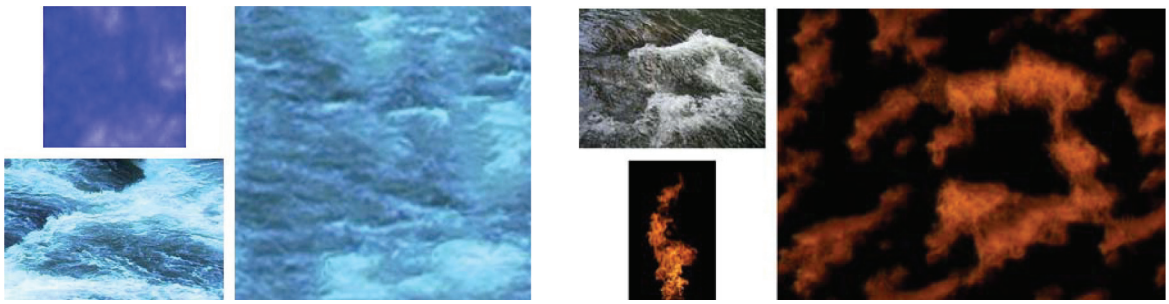
Selected Publications
V. Kwatra, D. Adalsteinsson, T. Kim, N. Kwatra, M. Carlson, and M. Lin. "Texturing Fluids," *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 2007, to appear.

R. Narain, V. Kwatra, H.-P. Lee, T. Kim, M. Carlson, and M. Lin. "Dynamic Feature-Guided Texturing of Continuous Flows," UNC Technical Report, 2007.



Feature-guided texturing: note the texture has more foam (is whiter) near turbulent regions of the fluid as expected.



Texture synthesis on video input: In each example, the upper video is used as the target behavior and the lower video is the source for texture examples. The generated video has the appearance of the source but behaves and flows like the target.