A Flexible Image Processing Approach to the Surfacing of Particle-Based Fluid Animation

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Abstract In recent years particle based techniques, like FLIP, have all but replaced Eulerian techniques for free-surface fluid animation in movie production. This, in turn, has put more emphasis on efficient tools that can turn point clouds into water surfaces. In this context one of the main challenges is to devise an approach that allows for both a high degree of artistic control as well as fast turnaround. In this paper we outline such a system that has found good use at DreamWorks Animation. The core idea is surprisingly simple and yet powerful: create flexible and complex surface processing by means of daisy chaining simple and fast surface operators.

We have developed a novel approach to the important problem of turning particle systems into surfaces that represent an animated air-water interface. This system is open sourced in the C++ library OpenVDB [1], and has been thoroughly battle tested at DreamWorks Animation during the production of “The Croods” [2] (see figure 1) and “How to Train Your Dragon 2”. A distinguishing feature of our system is the fact that it is based on a flexible combination of numerous fast surface processing operators, several of which are 3D generalizations of proven techniques from image processing. This greatly empowers artists to quickly customize and iterate in a more sequential and manageable manner, hence allowing a significant degree of artistic control which is paramount in any movie production. This is a departure from most existing surfacing systems that are based on more complex monolithic techniques that are relatively slow, typically employ non-intuitive parameters and offer limited artistic control. Examples of such monolithic turn-key systems that attempt to generate high-quality surfaces in a single computationally expensive step are techniques employing elliptic particle footprints, initially proposed in [3, 4] and subsequently in [5], and techniques using surface filters based on the solution of high-order parabolic partial differential equations, e.g. [6]. While such techniques are impressive in their own right, they have proved to be undesirable in production where artists prefer a faster and more layered approach in which a specific “look and feel” is progressively achieved by daisy chaining simpler surface operators. Cu-

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riously this approach is similar in spirit to most existing image processing or 2D compositing workflows.

Fig. 1 Example of particle skinning for Lagrangian fluid animation using our framework based on VDB and a sequence of highly customizable and multithreaded surface operators. Left: The input particles generated by a FLIP fluid simulator (Naiad). Note the low density of particles colliding with the character. Right: The resulting liquid surface represented by an adaptive quad-mesh. Note the presence of thin sheets and sharp feature on an otherwise smooth surface with little signs of spatial aliasing due to particle undersampling. This image is property of DreamWorks Animation.

Our technical contributions are twofold; foremost, as outlined above, the simple yet surprisingly powerful idea to base our framework on a rich toolbox of fast low-level surface operators that can be combined in any order since they share a common implicit representation. Second, to the best of our knowledge several of these 3D operators are novel, though many of them have strong ties to conceptually similar ideas known from image processing.

The proposed workflow has three fundamental stages: initialization, surface processing and meshing. The first step simply serves to quickly convert the particles to a representation on which all the subsequent operations can work. This choice of representation is a narrow-band level set that can be represented compactly with VDB [1], and offers excellent computational performance for complex surface deformations, which of course are a hallmark of liquid interfaces. The conversion from particles to signed distance fields is easily multithreaded since VDB supports efficient hierarchical CSG operations required when joining partial conversions performed by the different computational threads. To improve temporal coherence this stage also supports simple velocity stretching and attenuation of particle footprints to form teardrop shapes.

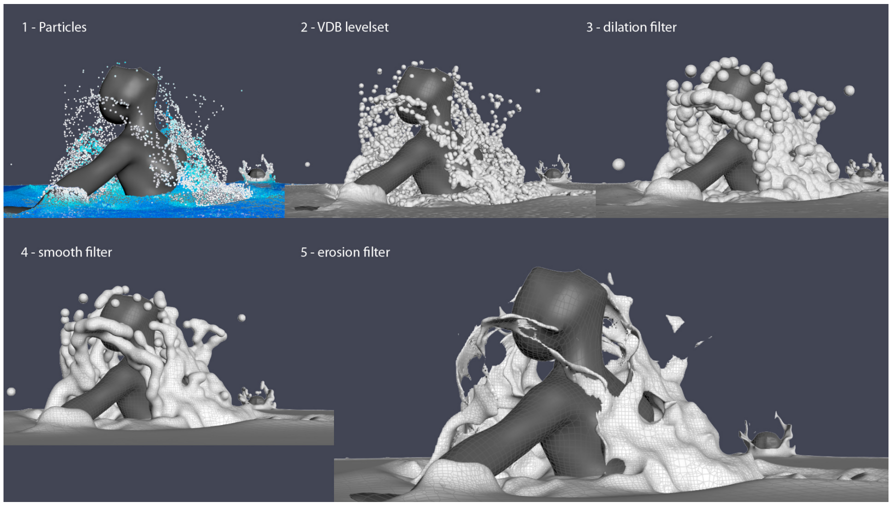

Fig. 2 Simplified illustration of a typical combination of surface processing operations for animated particle skinning: 1) Particles generated from any Lagrangian fluid simulation package. 2) Multithreaded conversion of particles into narrow-band level sets that merely serve as the initialization for our subsequent surface processing operators. 3) Dilation filter with interface tracking. 4) Application of various convolution filters with interface tracking, 5) Erosion filter with surface tracking. This image is property of DreamWorks Animation

The next (main) step in our pipeline applies different types of surface operators, all based on the implicit level set representation. We performed this post-processing of the initial particle surface by means of various combinations of custom filtering and morphological operations. These surface processing operators can be grouped into three distinctive kinds. The first group of tools is based on morphological operators like dilation, erosion, closing and opening. They effectively allow the artist to fill holes, remove small isolated particles, and sharpen, peak or blur surface details. Next, are smoothing operators that are based on differential properties of the level set surface. This includes mean-curvature flow and Laplacian smoothing that perform second-order smoothing operations. Last but not least, we use various types of kernel-based convolution filters that can smooth (or sharpen) surface details in a very computationally efficient manner. Examples include Gaussian, mean-value and median-value 3D filters that are applied directly to the signed distance fields. Unlike the curvature-based smoothing that solves parabolic PDEs, the kernel-based filtering techniques facilitate much faster surface deformations while still allowing for proper interface tracking and re-normalization of the narrow-band. This approach is especially attractive when employing filters that can be represented as a sequence of separable convolution kernels, e.g. box filters. As a simple but essential modification, these surface operators can all be augmented by arbitrary user-defined alpha-masks. This greatly enhances their usefulness since it allows artists to localize and better control the effects of an operation, for instance by deriving alpha-masks from differential properties of surfaces (e.g. curvature) or fluid velocity fields (e.g. vorticity). Alternatively these masks can also be created by painting directly on surfaces. Another very useful type of alpha-mask constraints the surface deformations to a user defined proximity to the input particles. Essentially this allows for the use of aggressive filtering and smoothing while preserving small surface details like ballistic water droplets. This idea was first proposed for polygonal surface in [7], but as demonstrated in [6] it is easily reformulated to level set surfaces. Figure 2 shows a simple example of a common combination of operators corresponding to a morphological closing that is interlaced with kernel-based filtering.

The final stage of our operator pipeline converts the narrow-band level sets to a polygonal mesh. Since VDB allows for very high resolution volumes we typically employ adaptive meshing techniques (e.g. a modified dual-contouring scheme) to greatly reduce the polygon count.

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