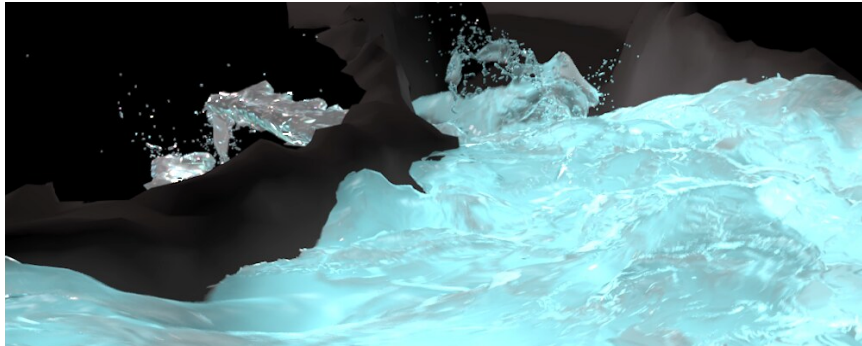# Monocoupled 3D and 2D River Simulations

Sanjit Patel, Jerry Tessendorf and Jeroen Molemaker

Rhythm and Hues Studios

1. Introduction

There have been several approaches to simulating the free surface of a body of water in high resolution. Keeping with a full 3D Navier-Stokes fluid solver, several authors have attacked the problem by using highly efficient methods of storing 3D grids [HNB*06], using tall cells [IGLF06] with low resolution at depth in the volume, and octree structures for the free surface [LGF04] to dynamically generated high resolution surfaces.

An alternative to simulating all of the free surface motion within a single approach, is to couple multiple simulations together in some way. A 3D "low resolution" simulation captures important motion of a river, including splashes. Water surface simulation based on 2D methods such as FFT [DEF*04] or iWave [Tes04] generate high resolution, but do not handle topological changes from splashing, etc. Coupling them can capture the best of both methods. In the present work, a dynamical coupling is implemented and the complex topology is produced by applying the iWave displacements to the CFD water surface via texture mapping.

We refer to our algorithm as a "monocoupling" of simulations, as opposed to a "bi-coupling", because the coupling is only one way: the 3D simulation drives the 2D simulation. The one-way only monocoupling is intentional for two reasons: (1) For artist workflow and control purposes, we want to simulate in 3D, then use the 2D as an enhancement on top of approved 3D simulation, and (2) our intent is to use the 2D simulation to capture motion on spatial scales smaller than the resolution of the 3D simulation. The physical mechanism that couples the surface displacement simulation to the 3D simulation is the advection process. Because the surface displacements ride on top of the evolving free surface,

they are carried along by surface currents. This is handled by advection terms in the 2D algorithm, motivated by the full nonlinear Bernoulli equation. The 2D simulation is an enhanced version of iWave, with advection added to it.

There are four components to our monocoupled simulation process: (1) 3D simulation of the river flow, (2) extract surface velocity as a 2D field for input to iWave, (3) 2D iWave simulation driven by the 3D velocity field and sources and obstructions in the flow, and (4) application of the vertical and horizontal iWave displacements back onto the 3D simulation surface as a displacement.

2. 3D Water Simulation

Fluid simulations in computer graphics take advantage of combining Eulerian and Lagrangian techniques. In our approach, particles represent a unit of volume rather than a distance to the levelset interface. This allows us to use the particles to correct volume loss, rather than correct the fluid interface. We use non-diffusive grid based techniques, such as QUICK advection [MCPN08], mixed with SPH particle simulations in situations and locations in which the levelset surface fails to adequately reflect the volume and action of the surface disturbance. Our hybrid method couples the Eulerian and SPH simulations via seeding, deleting, advancing, and merging of particles and levelset surface.

Seeding At the start of the simulation, particles are seeded non-overlapping and evenly distributed just inside the interface. As the fluid evolves, we march through the seeding band and add more particles where ever gaps occurs.
Deleting Since each particle represents a unit of volume, overlapping particles will lead to volume gain in the merg-

ing step. Using a static hash table for optimization, over-lapping particles are reduced to a single particle. Particles that move deep inside the levelset are also deleted.

Advancing Particles are advected using the same grid based velocity field as the levelset. Due to the nature of grid based techniques, thin features in the levelset cannot be represented. However, particles will be advected into correct regions where the levelset loses volume. When particles move outside the levelset, they are labeled as Outside particles. Outside particles evolve in an SPH simulation as described in [BT07].

Merging As the levelset and outside particles are evolving, particles occasionally reenter the levelset, where we preform a particle+levelset merge. At the voxel where the particle merges, the levelset value is set to the current voxel volume plus the particle volume. In addition, the velocity at the voxel is modified proportionate to the relative volume of particles vs levelset. This merge happens iteratively, since as the levelset grows, it can overlap more particles. Because the velocity field is modified, an additional mass converving projection is required before the velocity advection. When a number of outside particles cluster together, there is a particle+particle merge to convert the particles back into a levelset.

3. Surface Velocity and Displacement Mapping

The 2D surface simulation operates on a rectangular 2D spatial grid corresponding to the surface of the water. To couple this simulation with the 3D flow, the velocity field on the surface of the 3D flow is used to advect the 2D simulation. The 3D simulation produces a complex surface which may have splashes and other complex topological changes not well represented on a 2D grid. The velocity at the surface of the 3D simulation is extracted using a standard orthographic projection of the water surface onto a grid and sampling the velocity on that grid. At moments when the 3D simulation has ejected a volume of fluid that separates and flies over the main body, the orthographic projection finds the surface below the emitted fluid. Hence the extracted velocity field for the surface represents a continuous surface and is suitable for the 2D surface simulation. Later, when applying the 2D surface simulation as displacements, the same orthographic projection ensures that displacements are applied to the main body of water as a continuous surface. No displacements are applied to ejected volumes of fluid.

4. 2D Surface Simulation

The 2D surface simulation generates vertical and horizontal surface displacements which propagate as water surface waves. Because the simulation data is distributed on a 2D grid, it runs at much higher spatial resolution and simulation speed than typically achieved by full 3D Navier-Stokes solvers.

The basic surface simulation is the iWave algorithm [Tes04], but improved in three ways:

1. The second-order in time verlet-style solution has been converted to a first-order in time leapfrog solution for the surface height and the velocity potential. This form is more stable in our practice and allows for more augemtation with additional features.
2. Advection dynamics – omitted from the original iWave algorithm – has been implemented, including both non-linear self-advection and coupling to the surface velocity generated by the 3D simulation. This is the essential point where the 2D simulation is coupled to the 3D simulation, and the waves generated by iWave are transported along the water surface via advection.
3. Horizontal displacements are computed in the same fashion as the cuspy wave algorithm used for FFT-based ocean surface simultions [DEF*04]. This gives additional artistic control over the choppiness and turbulent appearance of the surface.

References

[BT07] BECKER M., TESCHNER M.: Weakly compressible sph for free surface flows. In *SCA '07: Proceedings of the 2007 ACM SIGGRAPH/Eurographics symposium on Computer animation* (Aire-la-Ville, Switzerland, Switzerland, 2007), Eurographics Association, pp. 209–217.

[DEF*04] DEUSEN O., EBERT D. S., FEDKIW R., MUSGRAVE F. K., PRUSINKIEWICZ P., ROBLE D., STAM J., TESSENDORF J.: The elements of nature: interactive and realistic techniques. In *SIGGRAPH '04: ACM SIGGRAPH 2004 Course Notes* (New York, NY, USA, 2004), ACM.

[HNB*06] HOUSTON B., NIELSEN M. B., BATTY C., NILSSON O., MUSETH K.: Hierarchical rle level set: A compact and versatile deformable surface representation. *ACM Trans. Graph. 25*, 1 (2006), 151–175.

[IGLF06] IRVING G., GUENDELMAN E., LOSASSO F., FEDKIW R.: Efficient simulation of large bodies of water by coupling two and three dimensional techniques. In *SIGGRAPH '06: ACM SIGGRAPH 2006 Papers* (New York, NY, USA, 2006), ACM, pp. 805–811.

[LGF04] LOSASSO F., GIBOU F., FEDKIW R.: Simulating water and smoke with an octree data structure. In *SIGGRAPH '04: ACM SIGGRAPH 2004 Papers* (New York, NY, USA, 2004), ACM, pp. 457–462.

[MCPN08] MOLEMAKER J., COHEN J. M., PATEL S., NOH J.: Low viscosity flow simulations for animation. In *2008 ACM SIGGRAPH / Eurographics Symposium on Computer Animation* (July 2008), pp. 9–18.

[Tes04] TESSENDORF J.: Interactive water surfaces. In *Game Programming Gems 4 (Game Programming Gems Series)*, Kirmse A., (Ed.). Charles River Media, Inc., Rockland, MA, USA, 2004.