

# Underwater bubbles and coupling

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## ABSTRACT

We present an approach to simulating underwater bubbles. Our method is sparse in that it only simulates a thin band of water around the region of interest allowing us to achieve high resolutions in turbulent scenarios. We use a hybrid bubble representation consisting of two parts. The *hero* counterpart utilizes an incompressible two-phase Navier-Stokes solve on an Eulerian grid with air phase also represented via FLIP/APIC particles to facilitate volume conservation and accurate interface tracking. The *diffuse* counterpart captures sub-grid bubble motion not “seen” by the Eulerian grid. We represent those as particles and develop a novel scheme for coupling them with the bulk fluid. The coupling scheme is not limited to sub-grid bubbles and may be applied to other thin/porous objects such as sand, hair, and cloth.

## CCS CONCEPTS

• Computing methodologies → Physical simulation.

## KEYWORDS

physical simulation, bubbles, coupling

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## 1 INTRODUCTION

Underwater bubbles are fascinating. Bigger volumes of air exhibit turbulent, almost explosive behavior as they shatter into mid-size, more stable pockets and myriads of tiny ones forming foggy aerated regions. The large density ratio between water and air (1000:1) is responsible for this beautiful violent dynamics, and is also a reason why bubbles are so difficult to simulate on a computer.

A number of papers have considered simulating underwater bubbles. [Goldade and Batty 2017] adopt a FLIP fluid simulator to represent each air pocket as a volume-conserving void with fixed pressure. While able to recreate realistic gargling water effects the

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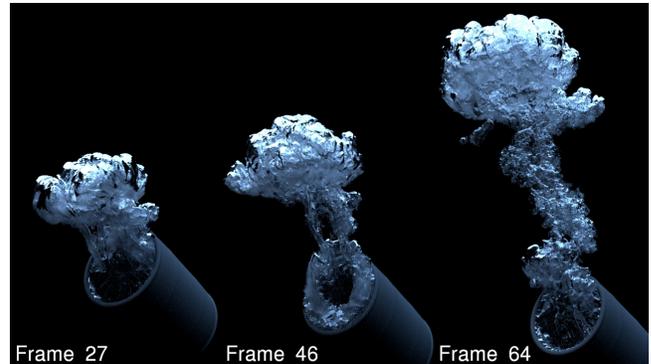


Figure 1: A large (~250 liters) barrel filled with air overturning under water is simulated with our method. ©Weta Digital Ltd 2020.

method does not capture subtle bubble details. [Boyd and Bridson 2012] use FLIP to discretize both water and air and perform a two-phase incompressible solve. Bubbles smaller than a grid voxel size are typically represented as a separate particle system. [Kim et al. 2010] passively advect those particles with the bulk fluid and use them to adjust effective density of water, leading to naturalistic buoyancy effects. They employ a stochastic solver for additional sub-voxel motion. [Patkar et al. 2013] use an Eulerian two-phase approach for simulating bubbles larger than the grid voxel size and passively advected particles for tracking bubbles smaller than the grid voxel size. They combine the two in a single linear solve which also handles compressibility.

## 2 OUR APPROACH

We disregard compressibility for efficiency reasons and adopt a two-phase incompressible ghost-fluid Eulerian solve for our *hero* (larger than the voxel size) bubbles, similar to [Boyd and Bridson 2012]. Unlike them however, we use FLIP/APIC particles to only track the air phase and recover the interface, while discretizing water as purely Eulerian in a narrow band around the bubbles. As we did not want the water to have an apparent sliding effect with respect to invisible boundaries and also to avoid dealing with null-modes in the Poisson pressure solve, we enforce hydrostatic pressure boundary condition, as opposed to a flux velocity boundary condition, on the outside of the narrow band  $p(h) = \rho_w g h$ , where  $h$  is the evaluation height. An example of a hero bubble simulation is shown in Figure 1.

We wanted our *diffuse* (smaller than the voxel size) bubbles to accurately capture sub-grid dynamics, unlike previous methods that would use them as tracers to modify the effective water den-

