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Expressive Rendering for 2D Animations of Liquids

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Abstract

We describe a new rendering technique for expressive liquid surface 2D animation that can be used on top of existing particle-based simulations. We introduce a hybrid particle model that carries both water and air density distribution and can evolve through particle history. These material quantities combined with the kinematics information are then used to generate a scalar field, which can be parameterized to create an implicit iso-surface capturing stylized geometry commonly seen in paintings and cartoons. We propose, in particular, to represent behavior highlighting the dynamical aspect of the scene, such as elongated droplet behavior and curl-like shapes found in breaking waves.

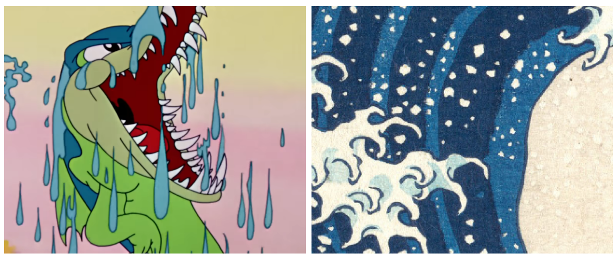
CCS Concepts

• ***Computing methodologies*** → *Shape Modelling, Implicit surfaces;*

1. Introduction

For many years, water animations have been used in movies, cartoons, video games, and scientific visualizations. Most research works have focused on the modeling and representation of realistic behavior of liquid [DHV*23]. Interestingly, stylized cartoons and paintings sometimes depict liquid using exaggerated representations featuring typically elongated droplet shapes or bulk associated with foamy surfaces (See Figure 1). These details seen by the geometry of the liquid surface are not aimed at describing realistic behavior but rather provide an expressive representation, helping the viewer to understand the dynamics of the motion. In this work, we explore the possibility of representing such stylized effects while still relying on standard fluid simulation. More precisely, we rely on an existing Smoothed Particle Hydrodynamics (SPH) simulation and enrich the particles to carry a local density field representing the presence of fluid and air around its position. The distribution of fluid and air varies over time based on the particle's history and dynamic properties. The liquid surface is obtained as an iso-surface from the global field computed by summing all individual contributions of the particles. By tuning the shape of the parametric field definition, the user can emphasize more or less the amount of stylization of the final liquid surface. Our contributions are twofold. First, we propose a velocity-dependent field representation allowing to model elongated droplets mimicking the effect from Figure 2(a); Second, we propose a time-varying model for air and water distribution around a particle allowing to model curly foam-like details on agitated waves similar to Figure 2(b).

Figure 1: *Different examples of artistic representations of water.*



(a) *Droplet example* **(b)** *Eraser example*

Figure 2: *Target effects for material representation*

2. Related Work

In computer graphics, air-water interactions are useful to offer more detailed and visually appealing representations of water for video games and movies [DHV*23, ACCK18] with foam and bubbles. A key aspect of this study is the air integration, Ihmsen et al. [IAAT12] defined a criteria with three characteristics to measure air entrapment, Bender et al. [BKKW19] improved this by adding vorticity as a fourth characteristic, Wretborn et al. [WFS22] propose

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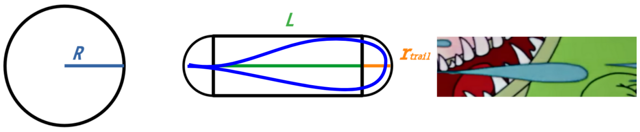


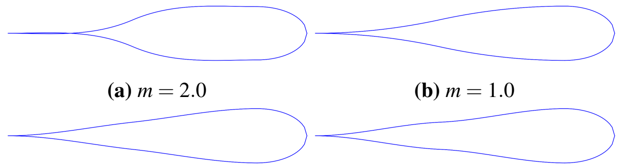
Figure 3: *The initial area is computed as a circle of radius R, and the expressive droplet should be contained in a shape composed by two half circles of radius r and one rectangle of height r and width L which is also the length of the skeleton.*

an aeration criteria based on particle stress, Baek et al. [BUH15] showed interaction between solids and liquid for muddy water.

Artistic representations of liquids is also an interest research topic, for example, while water droplets in real life are roughly spherical or circular, in animation, it is common to represent them as a combination of a half-circle with a trailing tail, creating a complex shape. In Figure 1, we present examples from both artworks and cartoon-style animations, highlighting the diversity of artistic approaches used to represent water. Artistic representations have also been applied in video games, Liu and Zhang [LZ13] used elliptical shapes to model splashes when interacting with ships or rocks, Neto and Apolinario [RNA14] worked on bubbles and foam for air-water interactions in video games, adopting a non-realistic style, Kim et al. [KAGS20] advect textures, such as paintings, over liquid surfaces using Lagrangian neural networks, Lee [LKLK19] use anisotropic shapes to represent droplets, though this method resulted in minor deformations, which differ from the more exaggerated artistic styles.
With respect to implicit surfaces techniques, volumetric representations with these ones have been extensively studied, Bloomenthal et al. [BBB*97] provide foundational examples that can be useful for our purposes. Additionally, insights can be drawn from works on body deformation animation [CD97, OC97, CGB16], which could be particularly relevant for the interaction of our particles due to the extra information that can be obtained from a neighborhood topology. Another area of interest is sketch-based animation [CSGC16, ATW*17], where advanced blending operators, such as those proposed by Gourmel et al. [GBC*13], play a key role.

3. Expressive Droplets

Although there are many artistic representations to choose from, we focus our work on the examples shown in Figure 2. In these one, a water droplet is depicted as a circle with a tail. The concave void at the crest of a wave can be use as references for representing bubbles and curvilinear details. For the droplet trail effect, we compute a skeleton for the droplet using the particle position of previous frames. Faster particles have longer skeletons with a trail and particles that doesn't move will resemble a normal circle. To achieve the trail shape, we use a decreasing radius function alongside the skeleton of the droplet. To compute the initial trail radius, we use the droplet's original area and the length of the skeleton, a depiction of this is shown in Figure 3. The radius computation is defined in (1).



(a) $m = 2.0$ **(b)** $m = 1.0$

(c) $m = 0.5$ **(d)** $m = 0.2$

Figure 4: *Different styles of trails obtained by changing the slope of the skeleton radius function.*

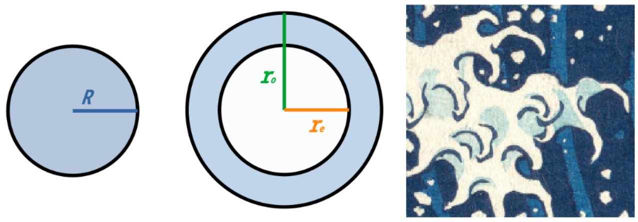


Figure 5: *The initial area is computed as a circle of radius R, and the eraser contains and amount of air for the sphere of radius r_e. Water can be found in the region between r_o and r_e.*

$$\pi R^2 = \pi r_{trail}^2 + L r_{trail} \\ r_{trail} \leq R \tag{1}$$

Where R is the original radius of the base area, L is the length of the skeleton and r_{trail} is the biggest radius to use on the trail of the droplet . To define what values of radius to use along the skeleton, we use a spline function with r_{trail} being the largest value use at the beginning of the skeleton. We can modify the slope of the radius spline and obtain different shapes as depicted in Figure 4. We found that a slope value within $[0.2, 1.2]$ produces trails that most closely resemble those in Figure 2(a).

4. Concave Effect

4.1. Air Integration

We define hybrid particles for air-water interactions. These particles have a constant amount of water and varying amount of air during the simulation. Variation of air quantity is divided in two process: Aeration and Release. The aeration measures how much air is trapped inside one particle and for this process we use the criteria of Wretborn et al. [WFS22]. The release defines how much air the particle will lose, now this a complex subject of study [Dei22, CBG*22], however, there are common notions related to release of air from liquids into the atmosphere [IAAT12, BKKW19, WFS22]. Values for both process can be normalized depending on user defined values which is pretty useful for this work. We use a particular model for air integration in this work but it can be extended to any model of air-water interaction as long as we can work with normalized values. The release will also have maximum and minimum values so it can be normalized and these values are also defined by the user. The amount of air added is defined in (2).

$$A_{air} = \int_0^N (\alpha I - \beta R)dt \tag{2}$$

Where I is the normalized air integration, R is the normalized air release and α is a fraction of area for contribution and β for release. The fraction values can be defined by the user. The total area of the particle A_p is defined by.

$$A_p = A_w + A_{air} \tag{3}$$

Where A_w is a constant representing the area of water and A_{air} is the contribution of air through all the time steps of the simulation. We defined the state of the particle as follows: Full Water and Eraser. Full Water is when there is no air inside the particle and it's represented by the droplet of the previous section. The second state is when the particle has a fraction of air inside and it produces the concave effect seen in Figure 2(b).

4.2. Shape Computation

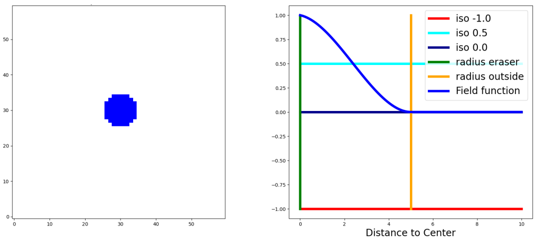
We achieve the concave shape using negative field function for the air part and a small positive field function for the water. We refer to as an "eraser"—an object that has a negative field function plus a small positive contribution. There is also a radius variation for the erasers since they have a mixture of materials inside which is depicted in Figure 5. For these ones, the radius variation is defined as follows:

$$\begin{aligned} r_e &= f(R, A_{air}) \\ r_o^2 &= r_e^2 + R^2 \end{aligned} \tag{4}$$

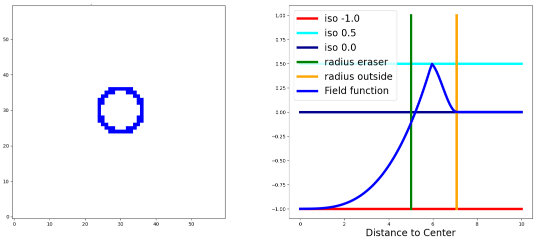
Where r_e is the radius associated with the air amount and r_o will define where we can find a small positive contribution of the eraser. We mention the negative contribution but we also need a small positive contribution in order to better represent the concave shapes found at the crest of the waves. For our density field function we propose an adaptation based on the kernel of Cani and Hornus [CH01]. SCAL-e [ZBQC13] is also a good option for examples in Figure 2 but it may impact heavily on the performance due to the amount of droplets. We formulate this field function using a cubic hermite spline in (3):

$$\begin{aligned} \phi_{[-1,1]}(d) &= h_{00}p_0 + h_{01}p_0^{'} + h_{10}p_1 + h_{11}p_1^{'} \\ p_0 &= 1.0,\ p_1 = 0.0 \text{ if } V_{air} = 0: \\ p_0 &= -1.0,\ p_1 = 0.5 \textit{ for } d < r_e \textit{ if } V_{air} > 0 \\ p_0 &= 0.5,\ p_1 = 0.0 \textit{ for } d >= r_e \textit{ if } V_{air} > 0 \end{aligned} \tag{5}$$

Where d is the distance of a point to the center of the eraser. The h values come from the spline definition. Values of d larger than r_o provide no contribution. The field function compute negative values only if there is air trapped. The iso-value $p_1 = 0.5$ is arbitrary but we found good results with it. The behaviour of the function can be observed in Figure 6 where we can notice the effect when there is no air and also how it behaves when we increase the amount of air. Please note that the maximal field value of a single eraser remains below the isovalue. As such, a single isolated particle in the air won't be representing water. However, once multiple particle interact together, these value may add up in order to model the transfer of water material outside of the empty concavity.



(a) A_{air} = *0.0*



(b) A_{air} = *1.0*

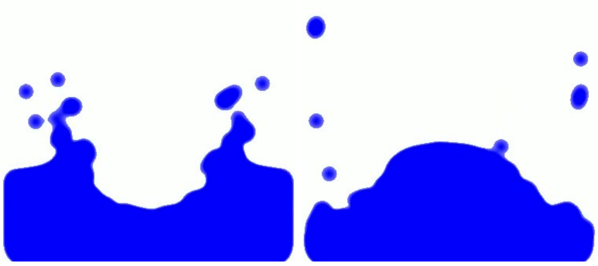
Figure 6: *Left: Water pushed to the outside when particle absorbs air. Right: Behaviour of the density field function with different amounts of air inside. Isovalue target for surface extraction is 0.5.*

5. Results

Two scenarios are going to be used for this test. First, a droplet falling on top of tranquil water to produce a splash and the expressive droplets with a trail similar. Second, a wave generator to produce where we have air-water interactions .

The sequence of the splash can be visualized on Figure 7 . Here, the droplets that fly away from the first splash are represented with a trail. The length of the trail and biggest radius of the droplet are also related to the motion of this one. It is worth noticing that both droplets flying alone and interaction between flying droplets resemble the ones observed in the cartoon animation like in Figure 2. For this visualization, we didn't add air so we could have a better visualization of the trail. In comparison to the baseline, we can clearly see the difference by using an expressive approach on the bounce and the consequent fall of droplets. While the baseline only represent spherical shapes, we managed to show these droplets with an artistic style.

The wave simulation test can be seen on Figure 8. The blue color denotes full water and the empty spaces within the liquid is the effect of the erasers. While we manage to achieve the effect of eraser for bubbles inside the liquid and the shapes of eraser appreciated in the Kanagawa great wave, some of them are in the wrong place. In Figure 8(c), we can see an eraser at the back of the wave. Also, we can't see a proper eraser at the crest of the wave, instead, we have a bubble inside the wave, an undesired effect for the wave. The bounce on the other hand show us how bubbles will look. While comparing our method to the baseline, we could notice that there



(a) *Baseline* **(b)** *Baseline*

(c) *Ours* **(d)** *Ours*

Figure 7: *Representation of two situations of the falling droplets. First we have the bounce of the splash(a,c) and the falling droplets after the bounce (b,d).*

(a) *Wave before climax.* **(b)** *Wave collapse.*

(c) *Wave before climax.* **(d)** *Wave collapse.*

Figure 8: *Visualization of waves animation, (a) and (b) is the baseline result while (c) and (d) use our method.*

is not significant difference for the climax of the wave but for the collapse we managed to generate extra effects that could resemble the spray of water and bubbles, something that cannot be achieved if we don't use the hybrid particles. So far we can say that we can achieve the effects that we want but we need to check our methods in order to replicate those effects on the correct places.

6. Conclusions and Future Work

We presented a non-photo-realistic method, inspired from art and cartoons, for rendering liquid animations. Our solution relies on multi-material implicit surfaces, through animated hybrid particles advected with the liquid, carrying multi-material field functions - namely water and air - which are adequately combined to form the rendered surfaces.

Although the initial results show some interesting shapes aligned with our goals, there still work to be done. The criteria for aeration and release have good basis but still need to be check if it's used properly. A representation for the foam still needs to be defined so we can have all the different representations of material that we need for the visualization.

In future work, allowing the interaction between particles only if they collide and until they are considered neighbors would be a useful extension, since it would both improve efficiency and better match our visualization goals. In addition, rather than starting from a given set of artistic references as we did, it could be interesting to provide a way to modify our work so we can incorporate different artistic styles. This could be done in conjunction with the reverse problem of sketch based animation.

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