Simulating Caustics due to Liquid-Solid Interface Menisci

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Outline

1. Introduction
2. Background
3. Modelling the Meniscus
   - Related Work
   - Meniscus Contour
   - Meniscus Profile
4. Rendering
   - Overview
   - Direct Illumination
   - Targeted Photons
5. Results

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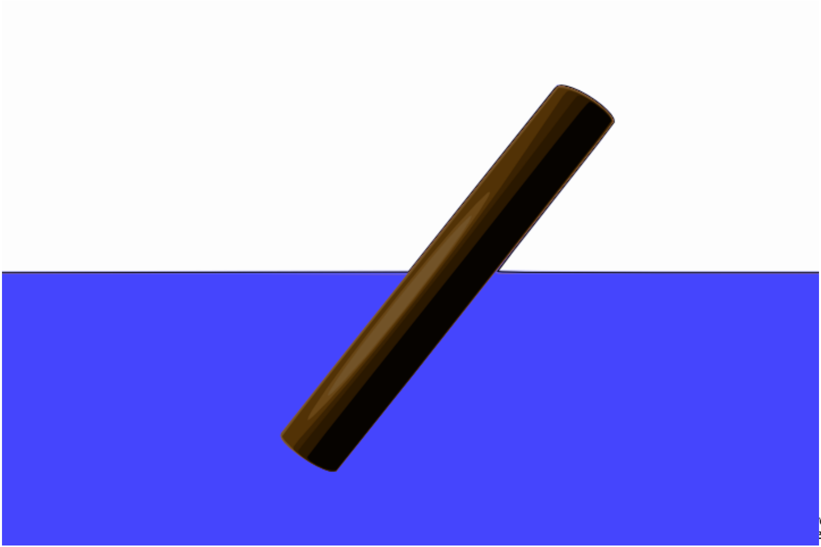

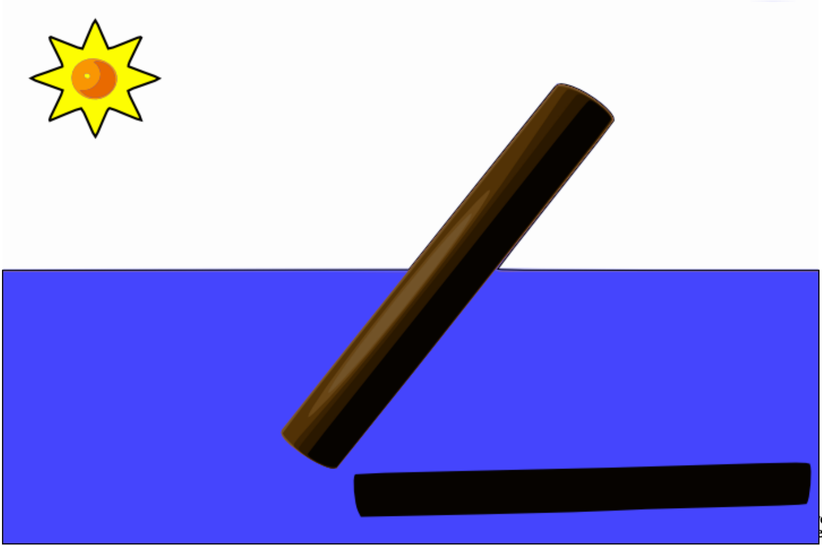

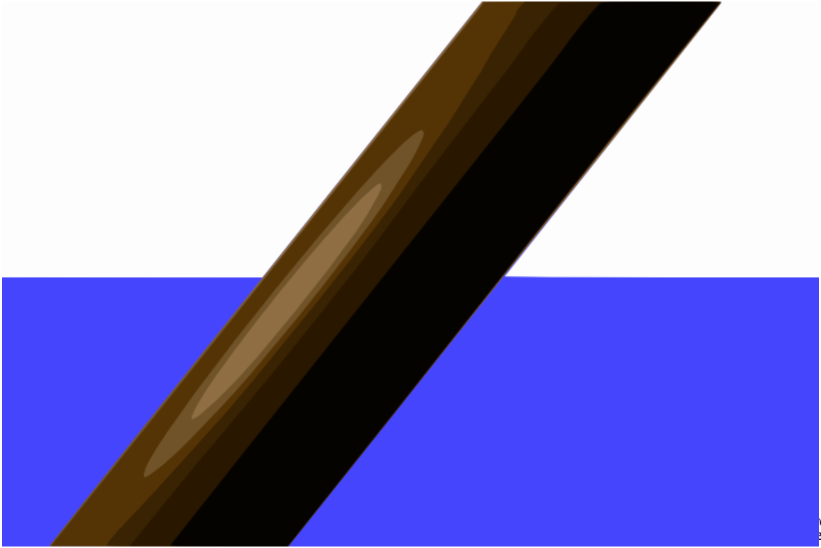

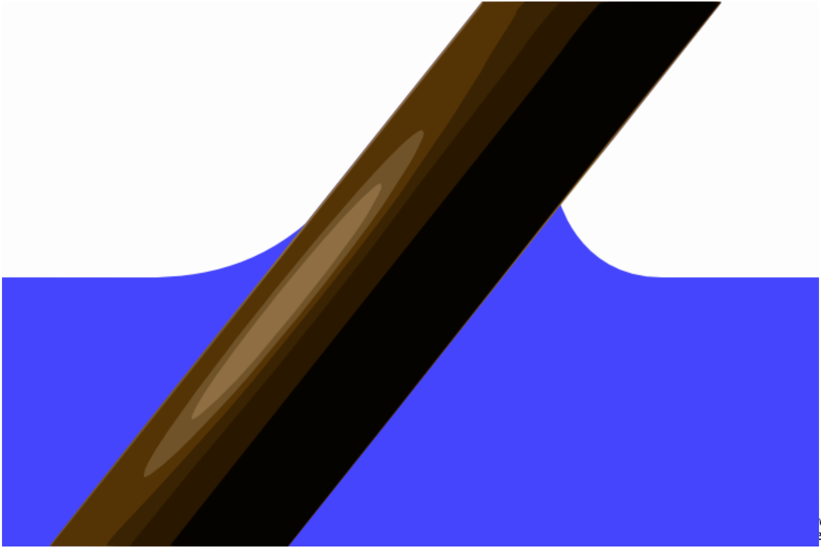

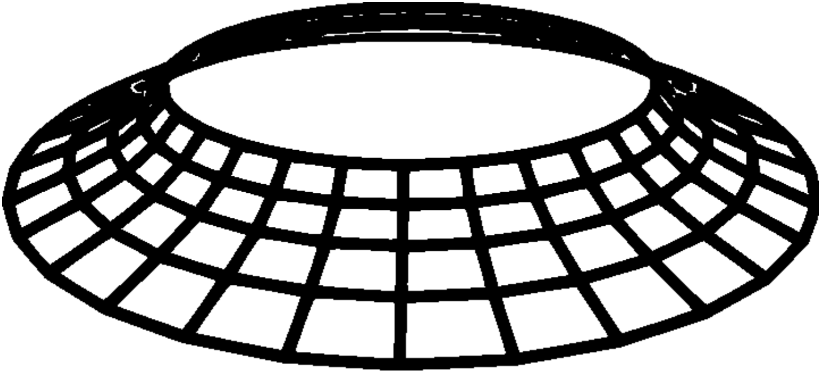

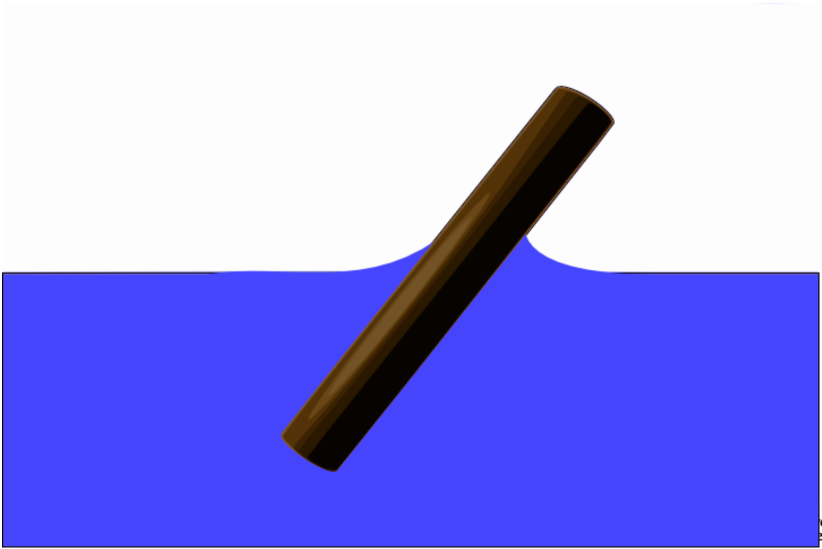

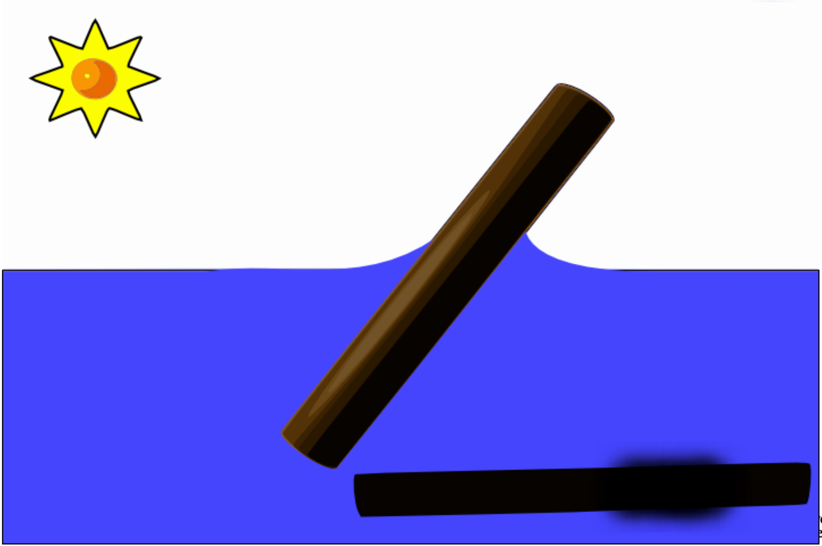

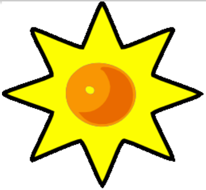

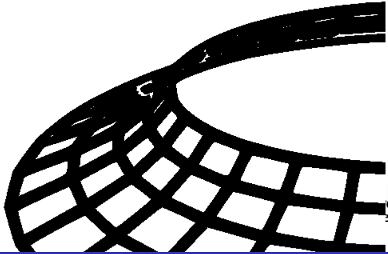

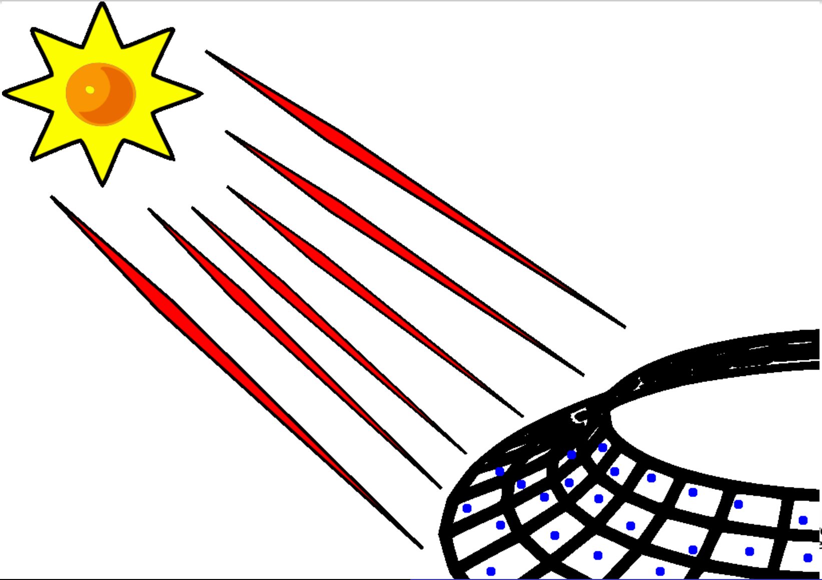

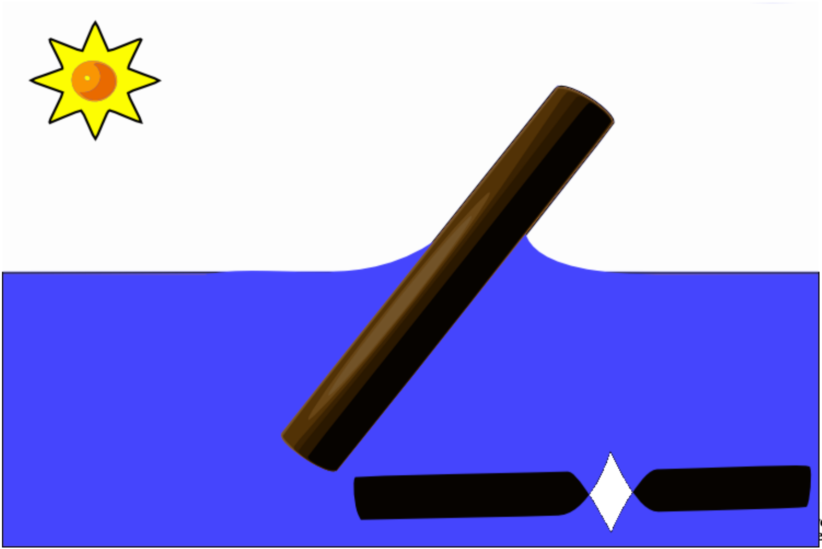

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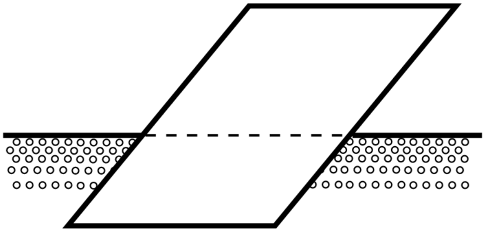
Molecular Forces



- Thin film of denser particles
- Surface molecules pulled up
- Acute angle - higher meniscus
- Obtuse angle - lower meniscus
- Convex profile if solid repels

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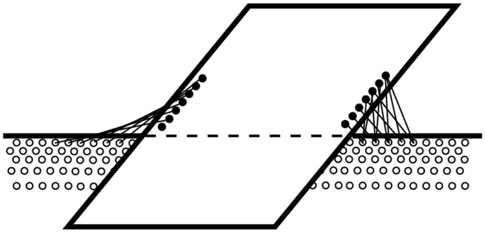
Molecular Forces



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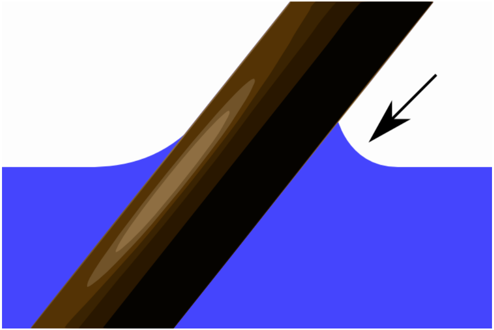

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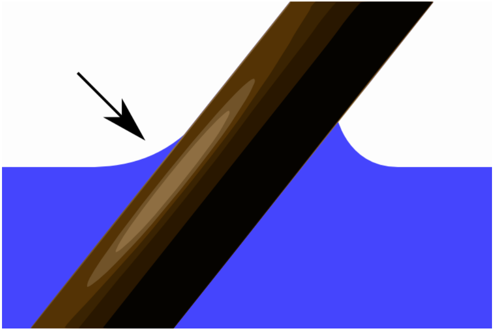

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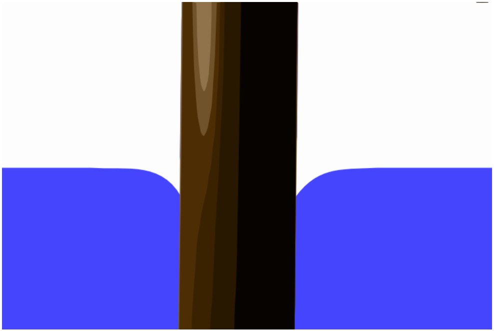

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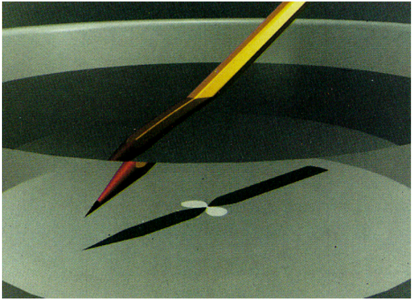
Related Work

Physics community

- Modelling the meniscus for a simple object (cylinder) is very complex:
  - Lock 2003
  - Berry 1983
  - Huh 1969
  - Adler 1967
- No generalisation for arbitrary intersection contours

Related Work
Graphics community



- Manually modelled meniscus - Watt 1990
- Interpolated normals of an elliptical annulus

We would like:

- arbitrary object intersections (meniscus shapes)
- automatic detection
- efficiency
- method to capture the lighting effects

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Calculating the Meniscus Contour

- Identify potential liquid-solid intersections (BVHs)
- Triangle-triangle intersection gives segments [Möller 1997]
- Link segments into contour polylines C
- Segment endpoints P_i have two normals, $\mathbf{N}_l$ and $\mathbf{N}_s$
- Contour normal $\mathbf{N}_c$ is $\mathbf{N}_s$ projected onto the liquid

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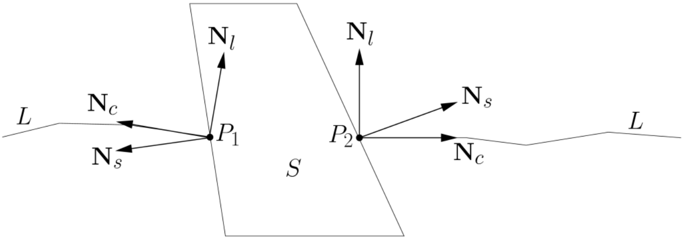

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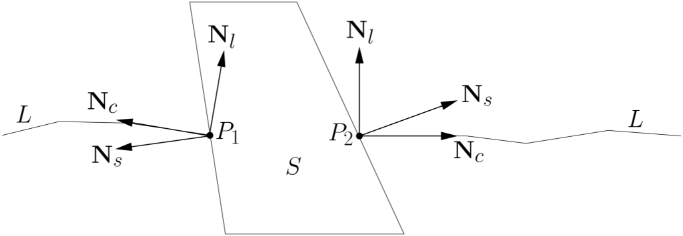

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Meniscus Profile Function

- We want a meniscal profile similar to analytic solution for cylindrical case
  - continuous
  - limited extent
  - contact angle
  - fast calculation

$$h(d, \alpha) = \left(\frac{-2L}{\pi} \alpha + 2L \right) \left(1 - \sin \left(\frac{d\pi}{2} \right) \right)$$

$d \in [0, 1]$ is the distance from the contour, α is the contact angle

Displaced Profile

- Raised contour point will not touch the solid in general
- Calculate a displacement **s** to snap raised contour to solid
  - analytic solution
  - ray-casting, sliding along the contour normal
- Use flat profiles with normals from profile function

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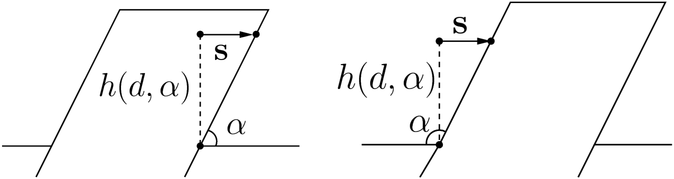

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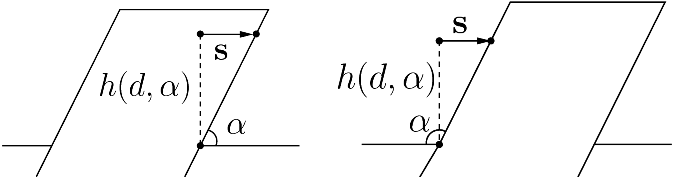

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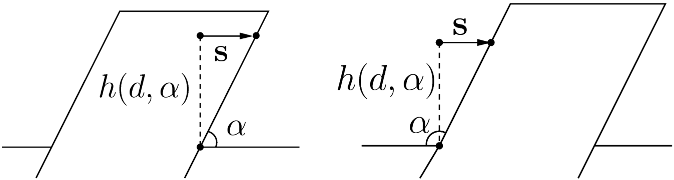

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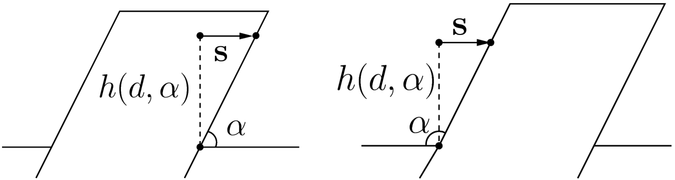

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Contour Tessellation

- *Grow* a tessellated contour at regular steps d along $\mathbf{N}_c$
- These are displaced along $\mathbf{N}_l$ by $h(d, \alpha)$

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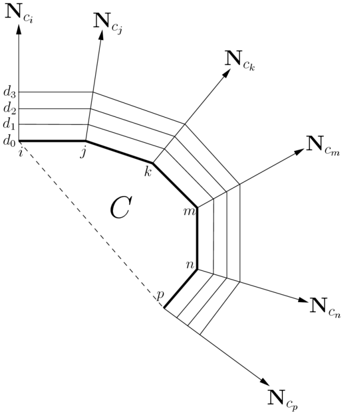
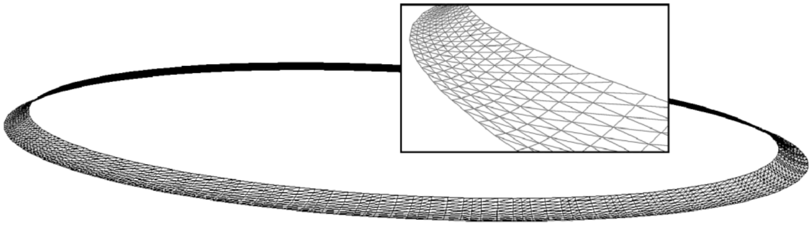


Meniscus Mesh Example



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Rendering

- Adding the meniscus geometry leads to 3 possible illumination changes:
    1. highlights on the meniscus itself
    2. caustics on the intersecting solid
    3. caustics on other surfaces in the scene

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Direct Illumination

- Size and curvature of the meniscus can produce highlights
- These thin bright highlights lead to aliasing
- Sample the normals within the projected pixel area

Approach

For any eye ray which intersects the meniscus, select the polygons within a given radius and average the shading results for *n* randomly sampled points in the radius.

- Differential ray mechanism determines appropriate radius [Igehy 1999]

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Targeted Photons

- 3D area-based sample on meniscus
- 3D area-intensity-based sample on light source
- Russian roulette to treat cosine factors
- Visibility test by ray casting
- Set photon power by light PDF at light sample
- Surviving photons are traced as usual
- Their interactions are stored in the targeted photon map

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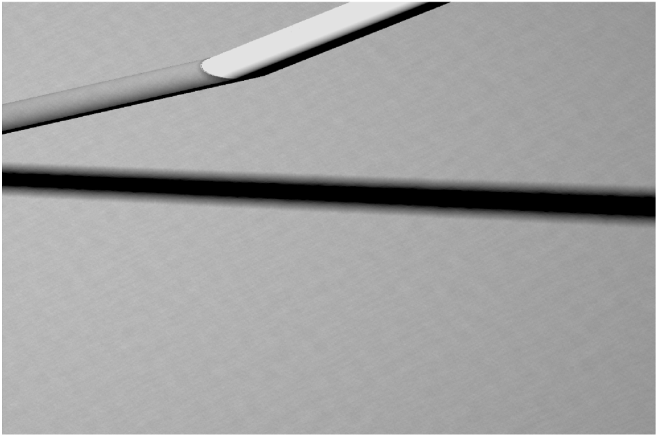
Implementation Details

- Implemented as plug-ins (liquid, photon map) in PBRT [Pharr 2004]
- Images in EXR with contrast-based tone mapping [Ward 1994]
- Meniscal calculation and targeted photons contribute negligibly to the rendering time

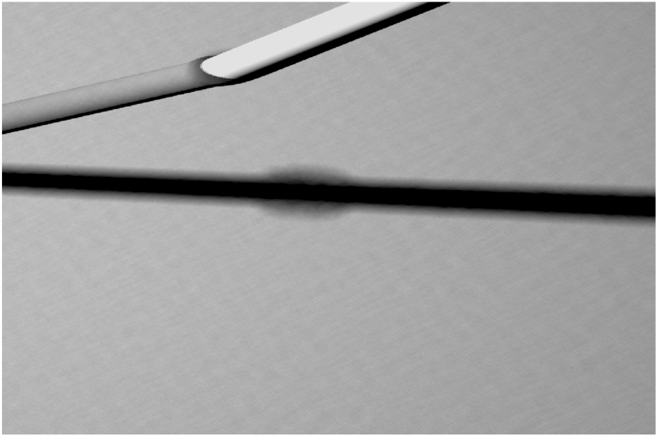
Photon Mapping

Without a meniscus

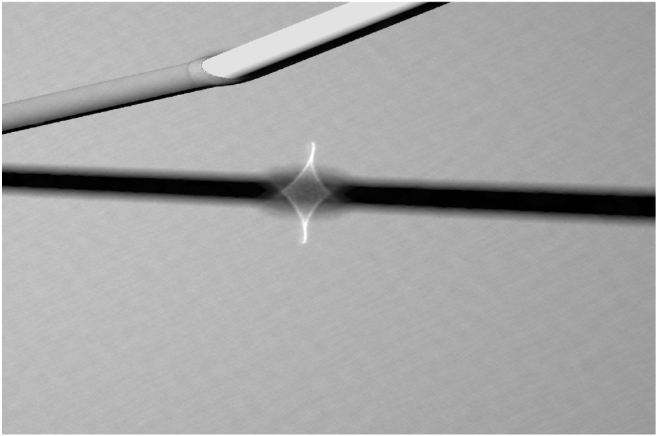


Photon Mapping

With a meniscus - no specialised sampling

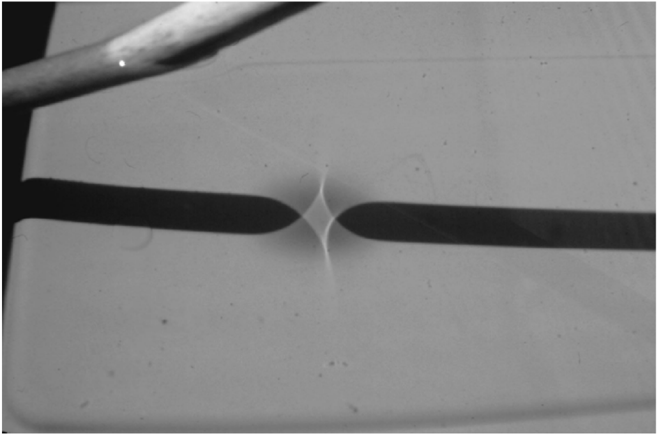


Photon Mapping
Our simulation using targeted photons



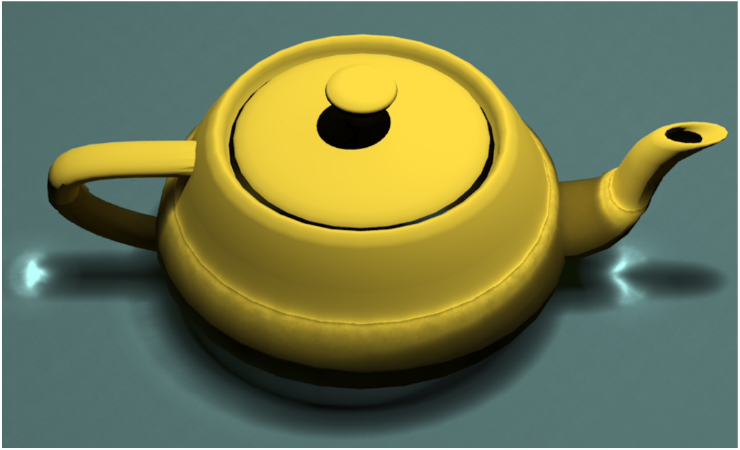
Real World Example

Shadow-sausage effect

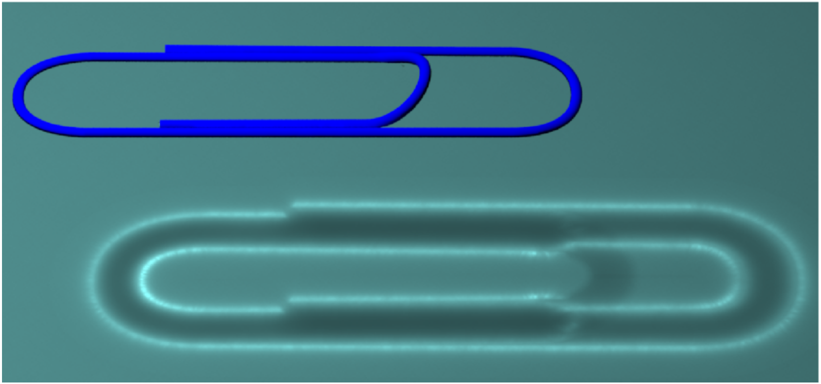


Real Teapot

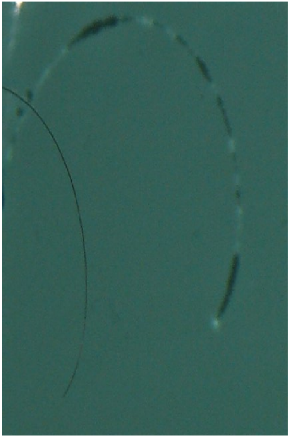
Synthetic Teapot

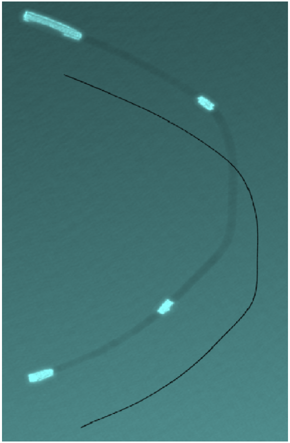


Paperclip

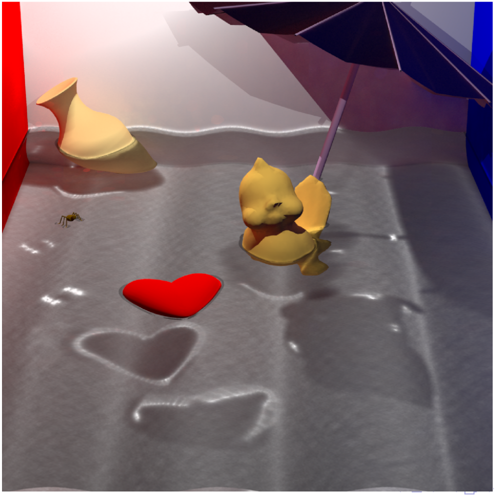


Synthetic and Real Hair





Multiple Objects, Lights, and Wavy Water



Summary

- automatically compute contours of arbitrary liquid-solid intersections
- build tessellated menisci from these contours
- render meniscal caustics using the targeted photon map
- results very similar to real-world scenes despite simplifications

Acknowledgements

- NSERC and FQRNT for their financial support
- Simon Bouvier-Zappa and Yann Rousseau for their artistic endeavours
- Anonymous reviewers for their valuable comments

Different Profile Functions