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Perceptual Evaluation of Liquid Simulation Methods

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Motivation

Fluid simulation methods	
Grids (or hybrid)	Particles
Level set (LS)	Smoothed particle hydrodynamics (SPH)
Fluid-implicit-particle (FLIP)	Weakly compressible SPH (WCSPH)
Affine particle-in-cell (APIC)	Implicit incompressible SPH (IISPH)
⋮	⋮

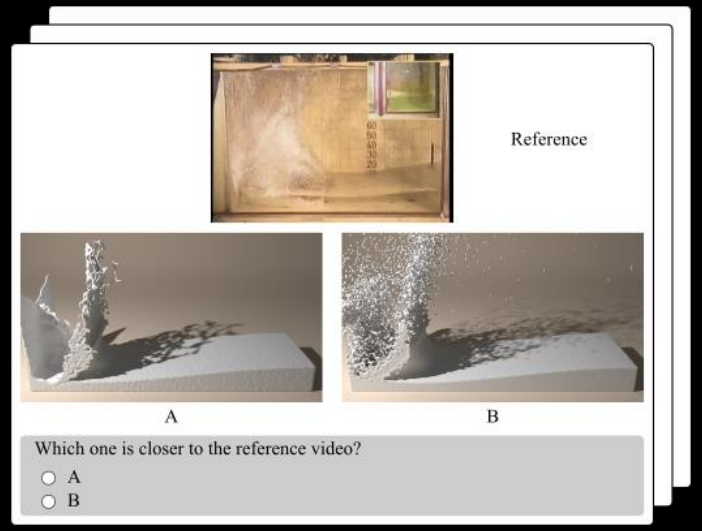
Visually better?

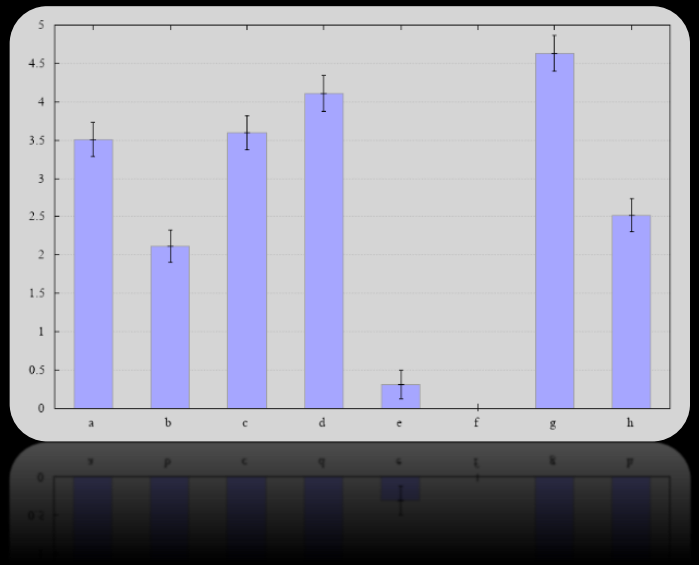
Overview

Different simulations for a setup

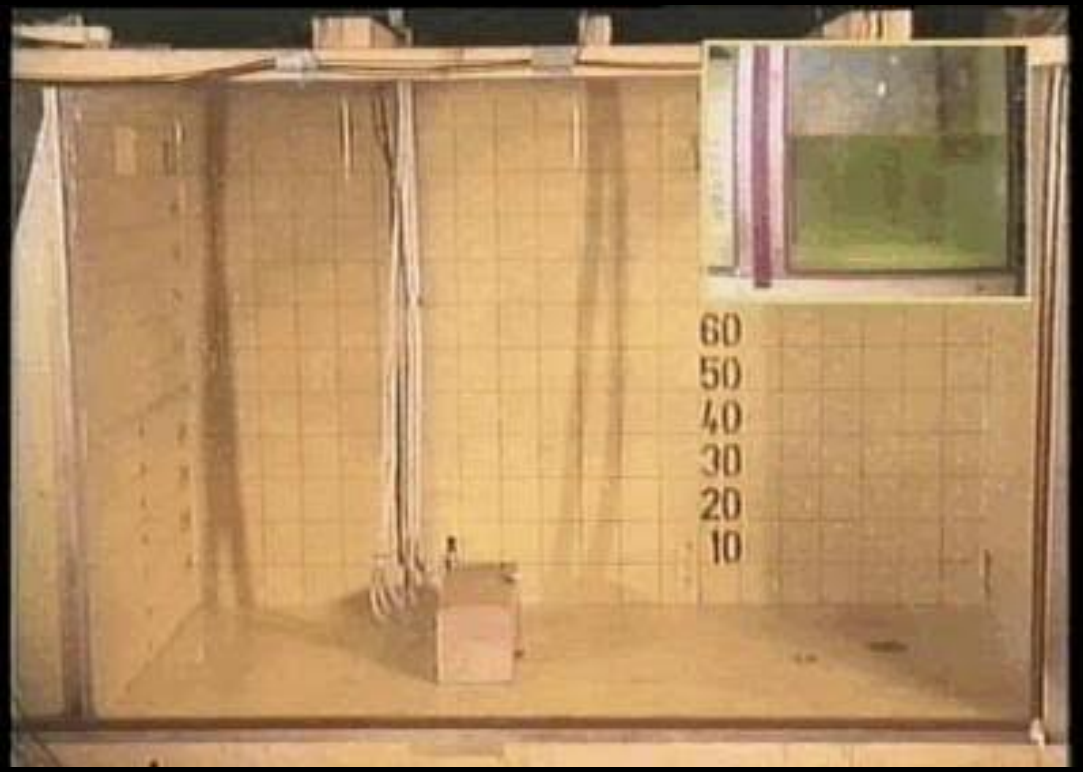
User study with pair-wise questions using a crowd-sourced platform

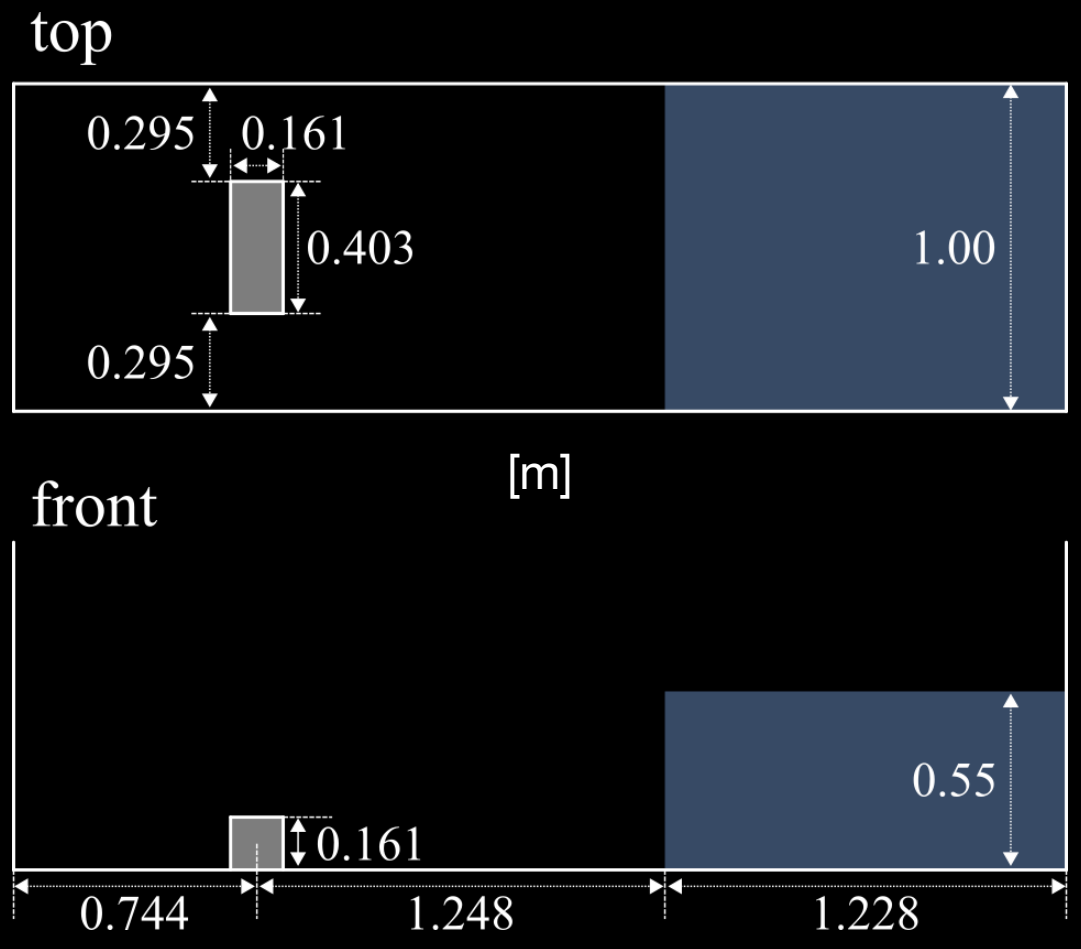
Evaluation scores





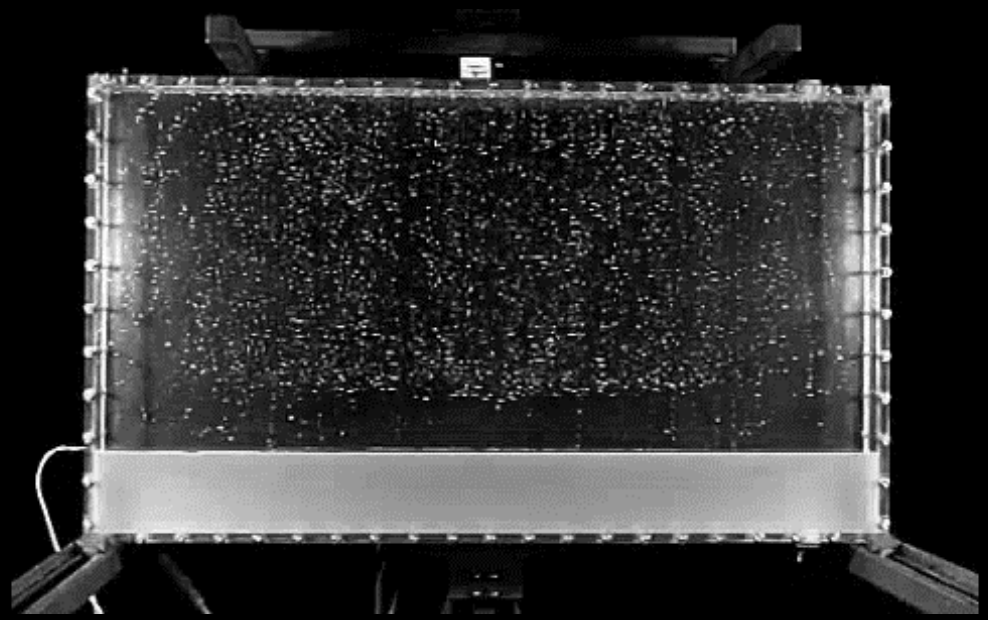
Simulation Setup: Dam

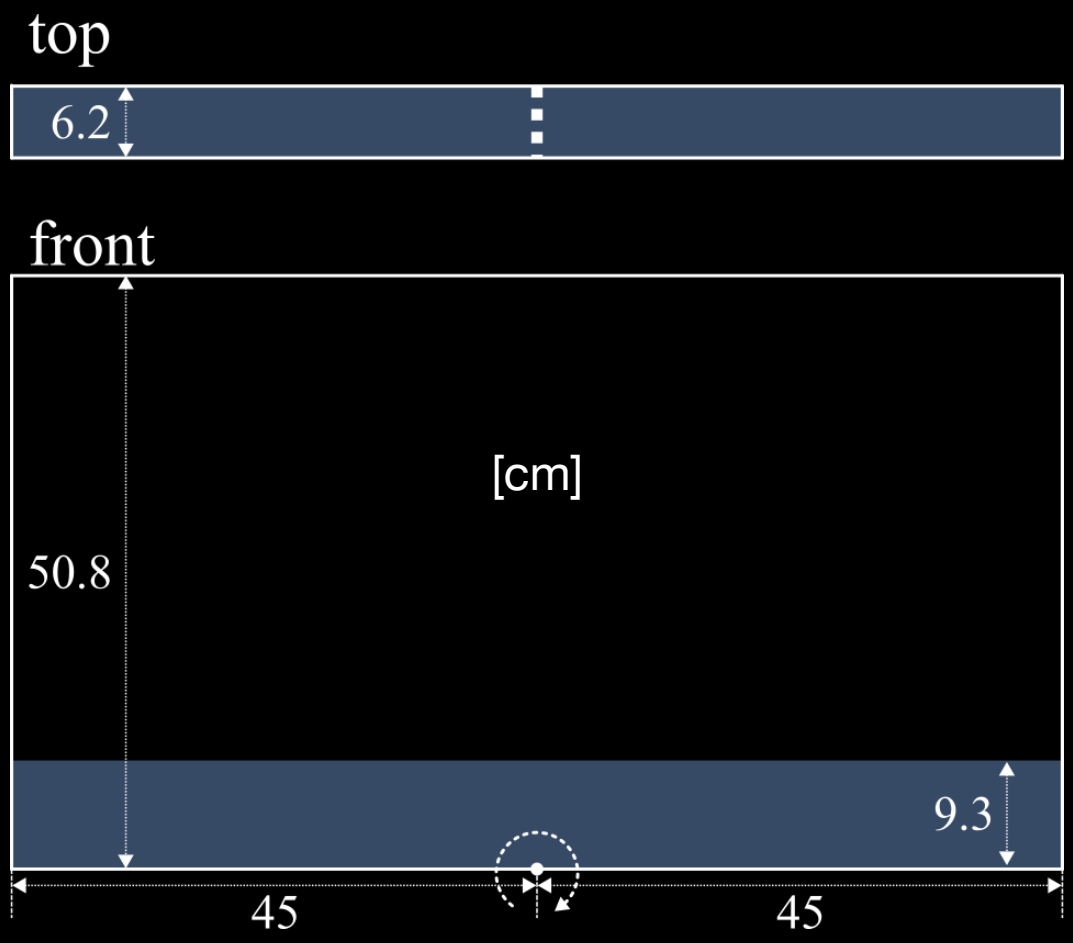




[Kleefsman et al., 2005, *A Volume-of-Fluid Based Simulation Method for Wave Impact Problems*, JCP]

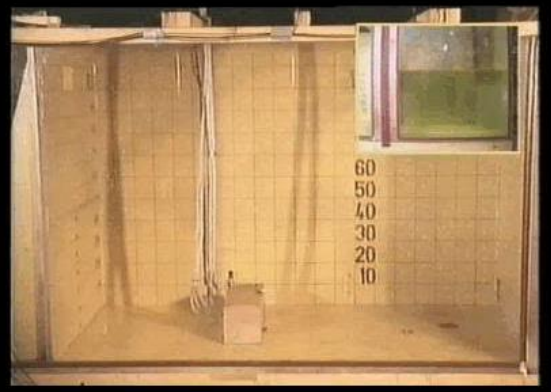
Simulation Setup: Wave



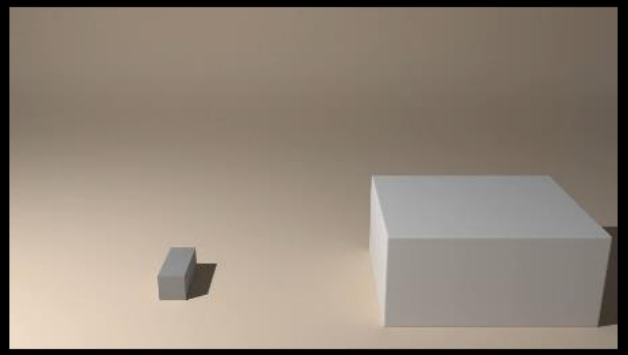


[Botia-Vera et al., 2010, *Three SPH Novel Benchmark Test Cases for Free Surface Flows*, ERCOFTAC SPHERIC workshop]

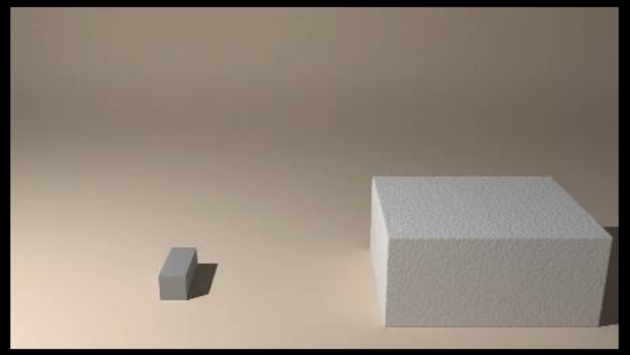
User Study Design



Reference



○ A



○ B

Which one is closer to the reference video?

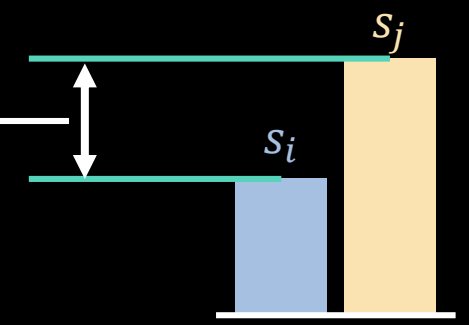
Visual Accuracy Scores

A set of pair-wise votes for m videos from a user study

The Bradley-Terry model [Bradley and Terry, 1952] to compute the score s_i of the video i

(p_{ij}: the probability that a participant chooses i over j)

$$p_{ij} = \frac{e^{s_i - s_j}}{1 + e^{s_i - s_j}}$$



The log likelihood (w_{ij}: the wins of i over j)

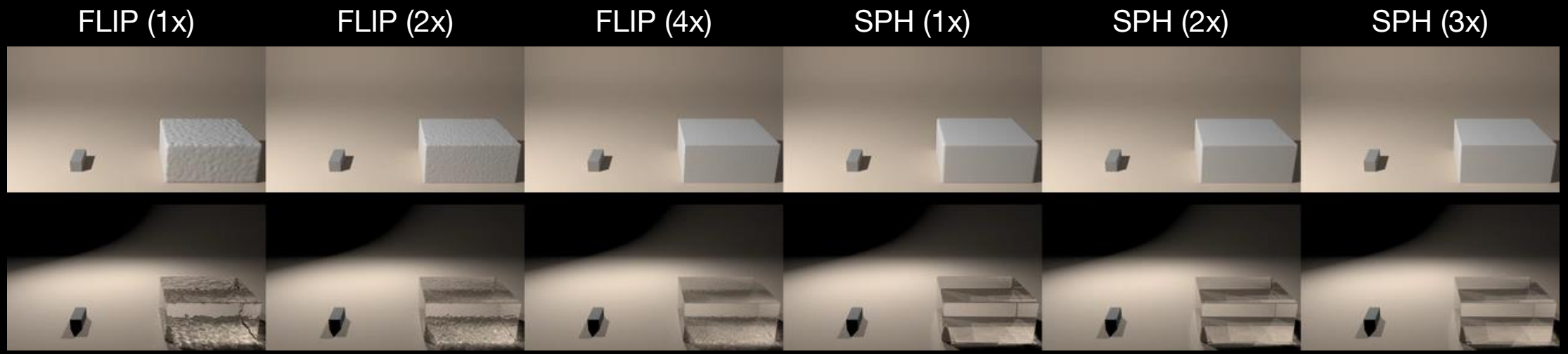
$$L(\mathbf{s} = [s_1, \dots, s_m]) = \sum_{i=1}^{m} \sum_{j=1}^{m} \left(w_{ij} s_i - w_{ij} ln(e^{s_i} + e^{s_j}) \right)$$

[Bradley and Terry, 1952, *Rank Analysis of Incomplete Block Designs,* Biometrika]

Different User Studies

6 videos of dam using FLIP & SPH (3 resolutions per method)

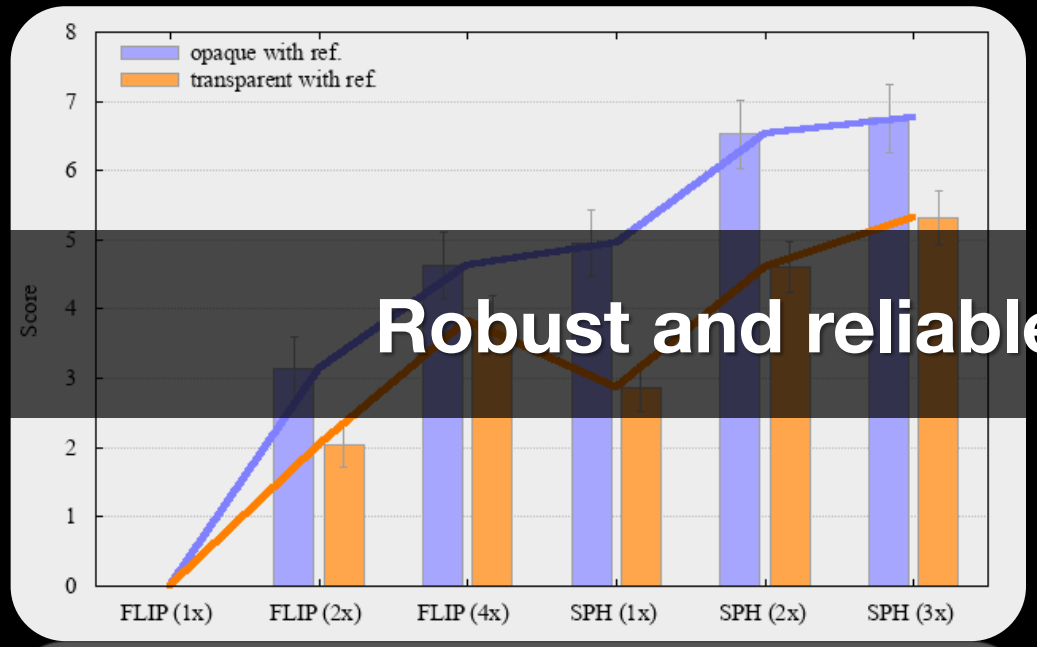
Rendered in opaque & transparent



Effect of the Reference Video

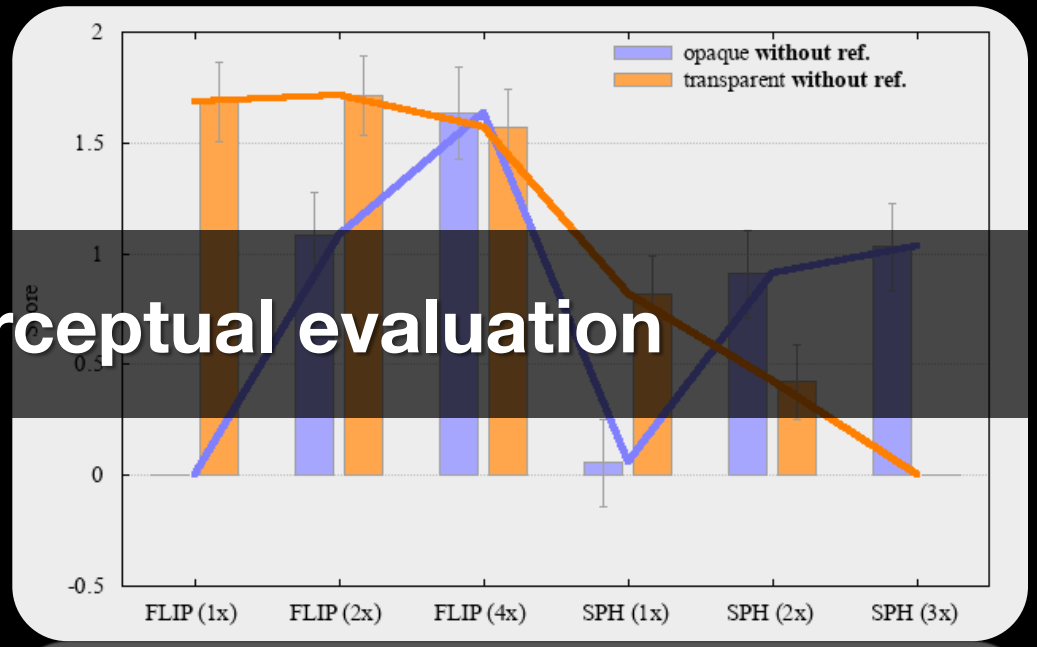
Correlation among the sets of scores from the studies

With reference



Strong positive correlation

Without reference



No or weak correlation

Robust and reliable perceptual evaluation

More Rendering Styles

Two additional styles: glossy & translucent

- Additional user studies with the reference video

User Studies with Wave

6 opaque videos of wave with FLIP & SPH (3 resolutions per method)

With & without a reference video

FLIP (1x) FLIP (2x) FLIP (4x) SPH (1x) SPH (2x) SPH (3x)

Comparison of two studies	Constant parameter	Correlation
dam vs. wave	with reference	O
dam vs. wave	without reference	O

Beyond the Experimental Video

User studies for dam with different reference videos: seashore & wave

6 opaque videos using FLIP & SPH

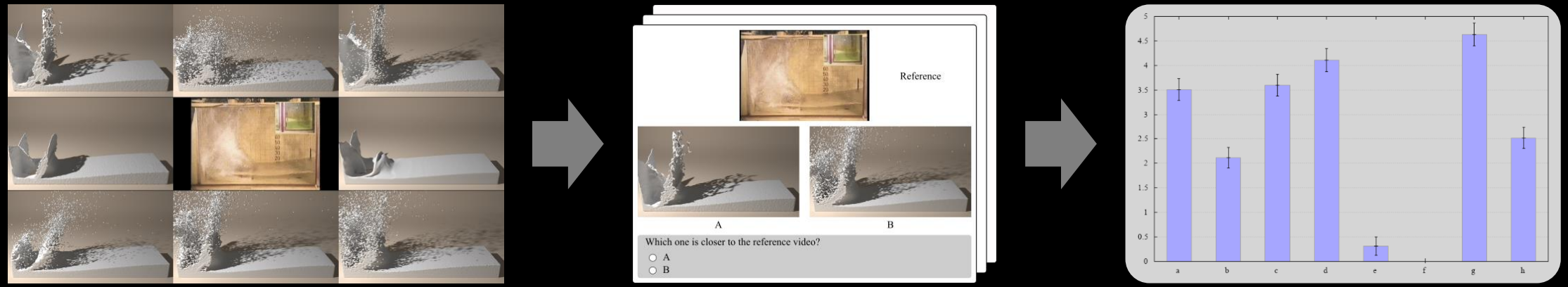
Different Representative Methods

User studies with different simulation methods

- APIC & IISPH (vs. FLIP & SPH in the original studies)
- 6 opaque videos of the same setups for dam

Comparison of two studies	Constant parameter	Correlation
FLIP&SPH vs. APIC&IISPH	with reference	O
FLIP&SPH vs. APIC&IISPH	without reference	O

Our perceptual evaluation framework

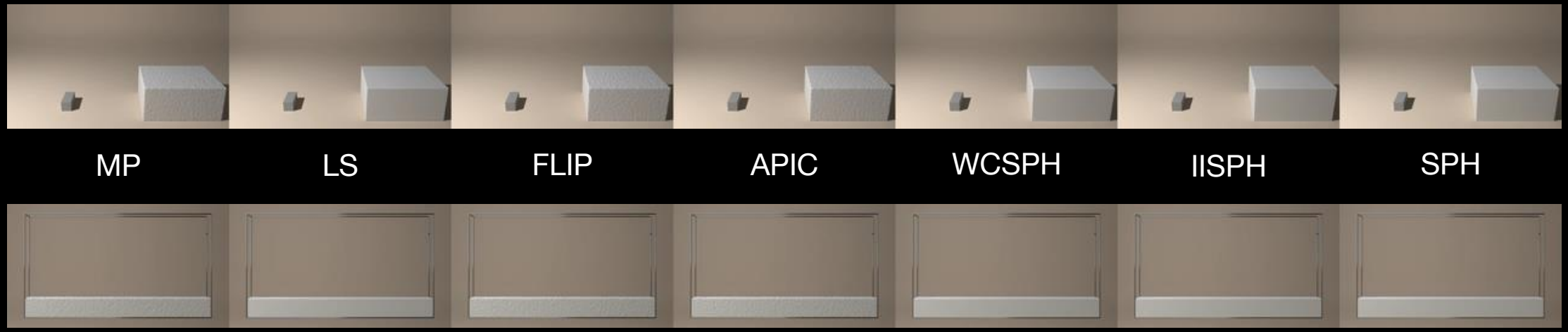


Applications

Application: Different Methods

Compare various simulation methods

- Grids (or hybrid): Marker-particle (MP), LS, FLIP, and APIC
- Particles: WCSPH, IISPH, and SPH

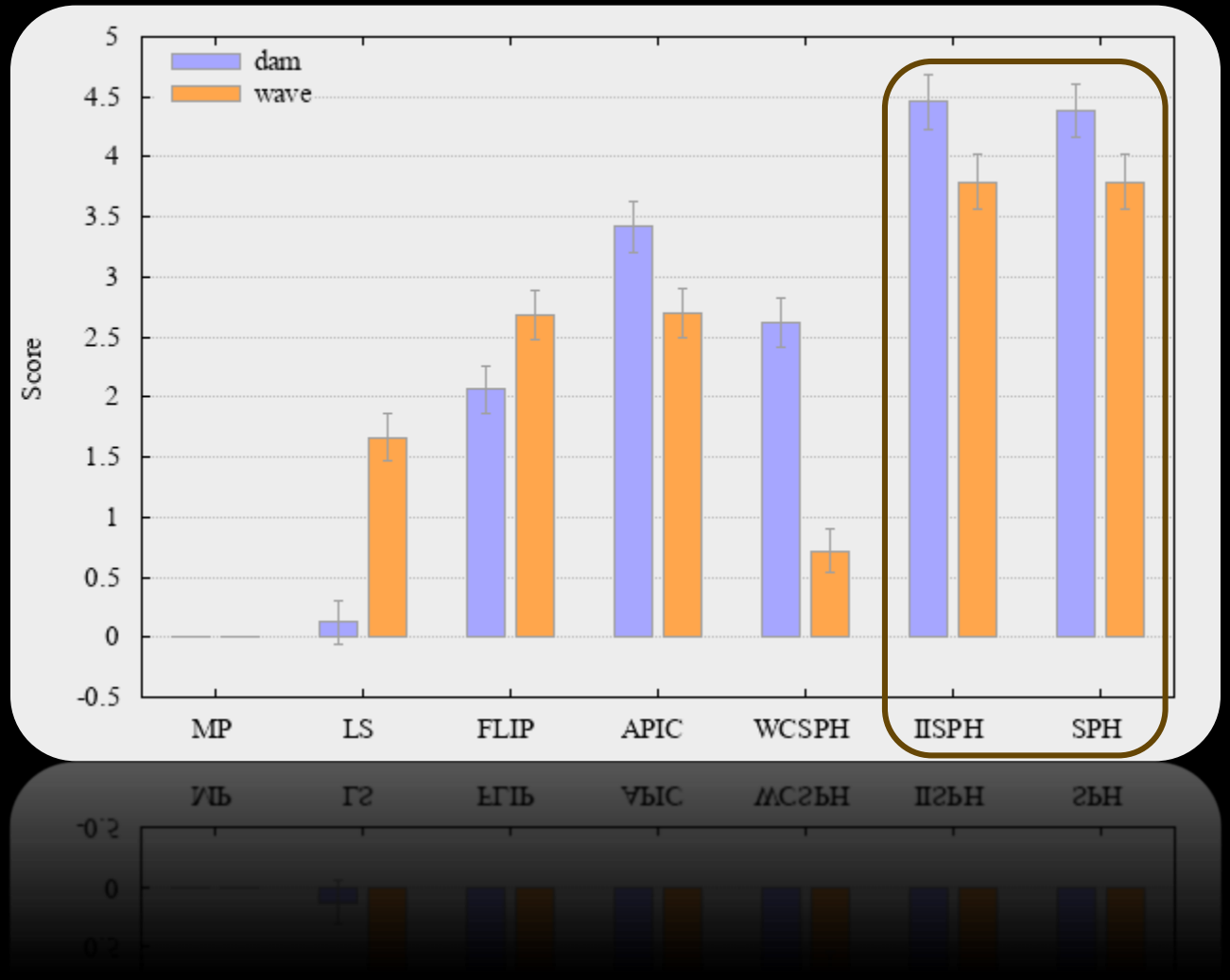


Application: Different Methods (cont'd)

$$p_{ij} = \frac{e^{s_i - s_j}}{1 + e^{s_i - s_j}}$$

IISPH vs. FLIP

$$\frac{e^{4.5-2}}{1 + e^{4.5-2}} \approx 0.92$$



Application: Performance

Similar computation time:

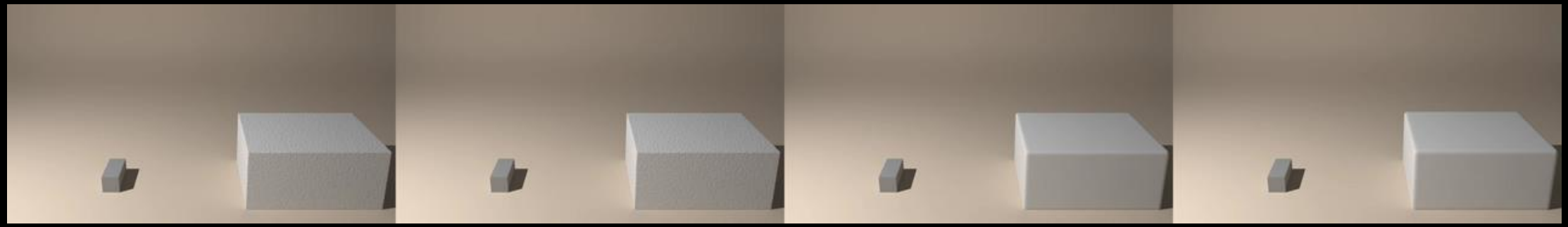
~55 seconds / frame

Resolutions:

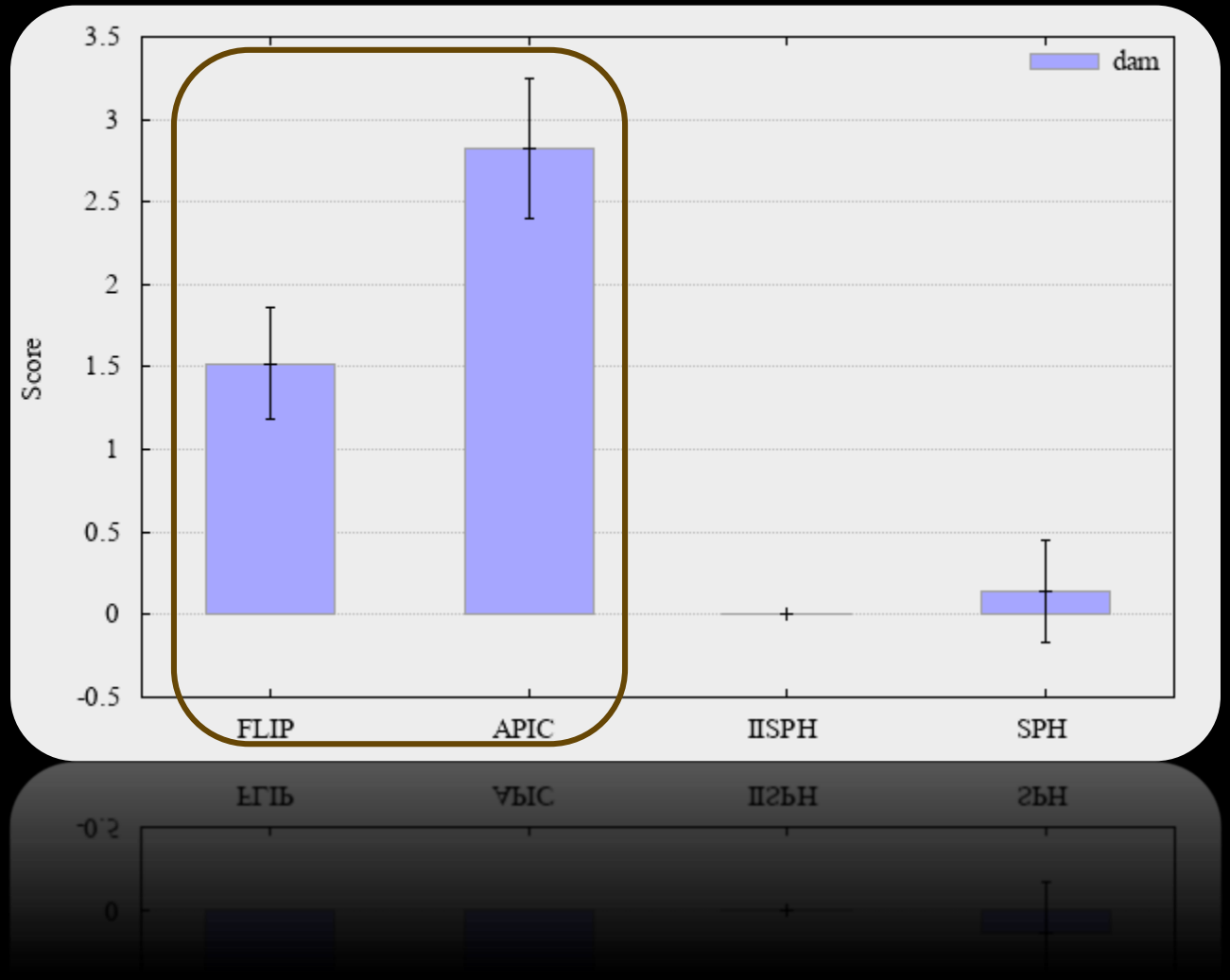
320x300x100 grid and 5m particles for both FLIP & APIC

143k and 84k particles for IISPH & SPH

FLIP APIC IISPH SPH



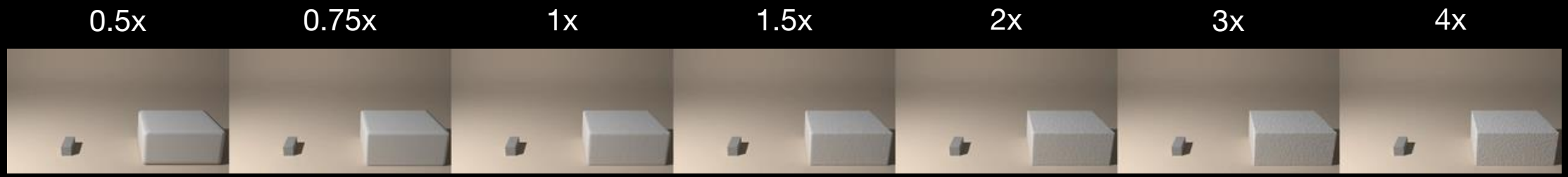
Application: Performance (cont'd)



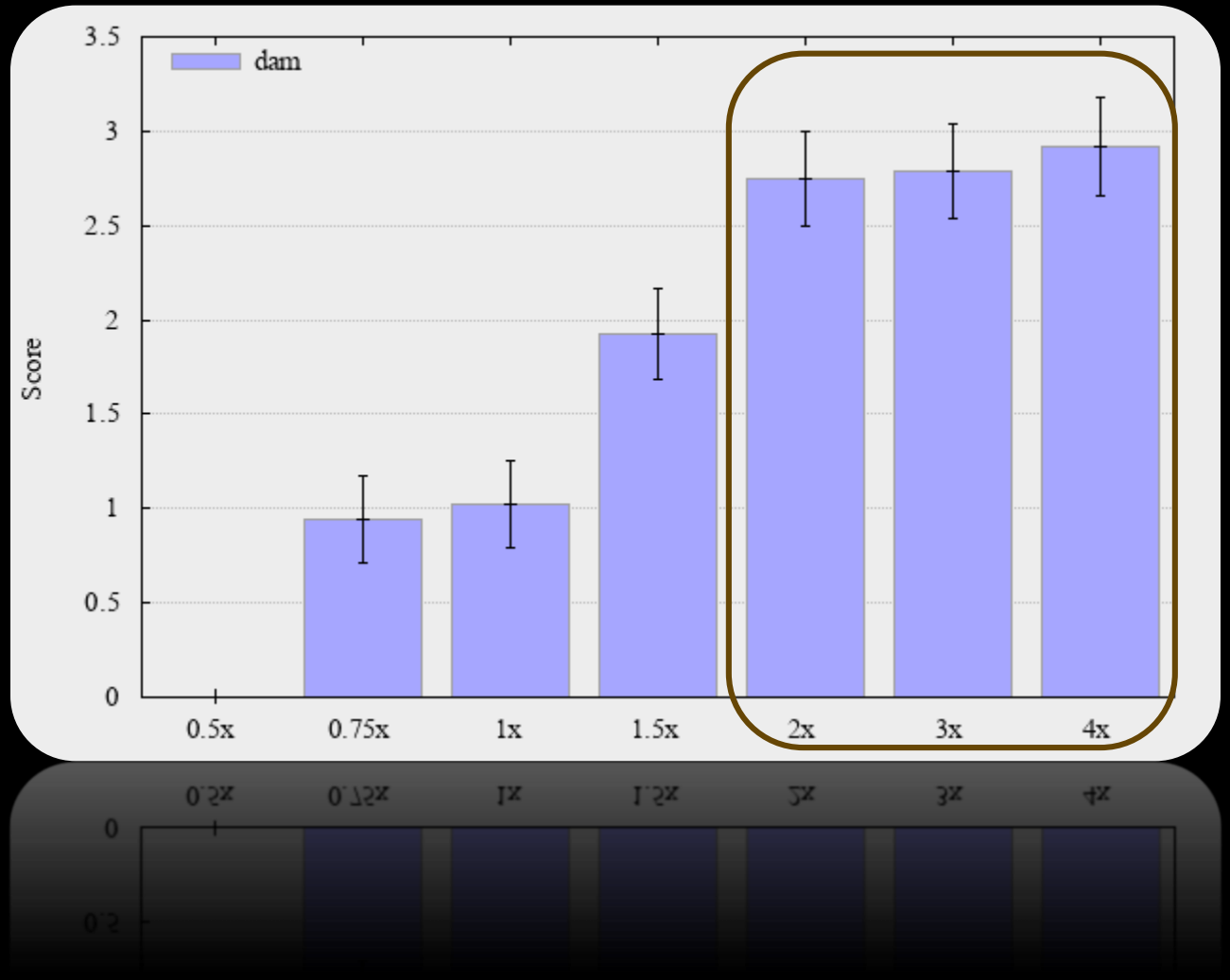
Application: Particle Skinning

Revisit a heuristic approach

- Particle spacing: h
- Grid spacing for FLIP simulation: $2h$ (e.g., 160x150x50)
- Heuristic grid resolution for particle skinning: 2x (e.g., 320x300x100)



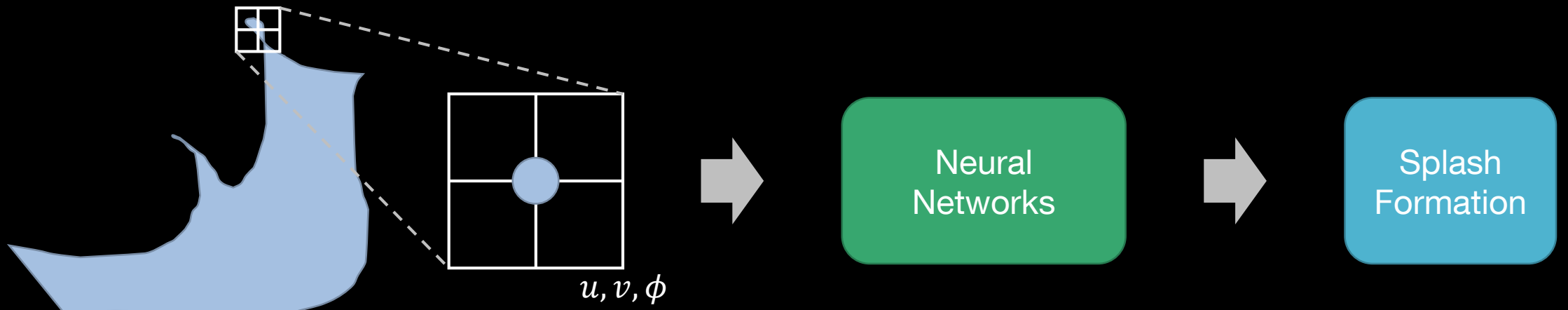
Application: Particle Skinning (cont'd)



Application: Splash Modeling

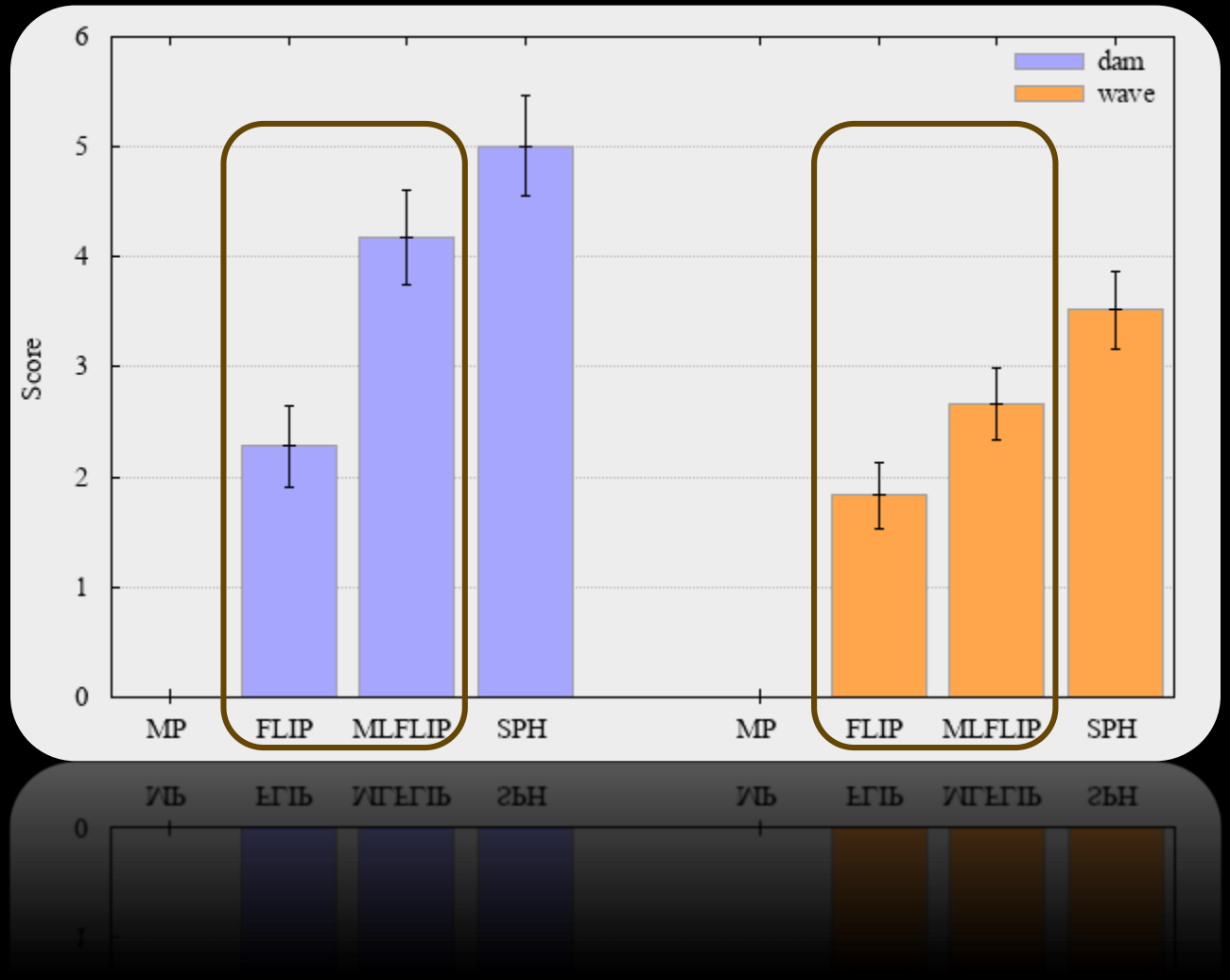
Inspect a FLIP extension: MLFLIP [Um et al., 2017]

Improvement of splashes using machine learning



[Um et al., 2017, *Liquid Splash Modeling with Neural Networks,* arXiv]

Application: Splash Modeling (cont'd)



Conclusions

A novel framework

- Robust and reliable perceptual evaluation of liquid simulation methods
- Crowd-sourced user study

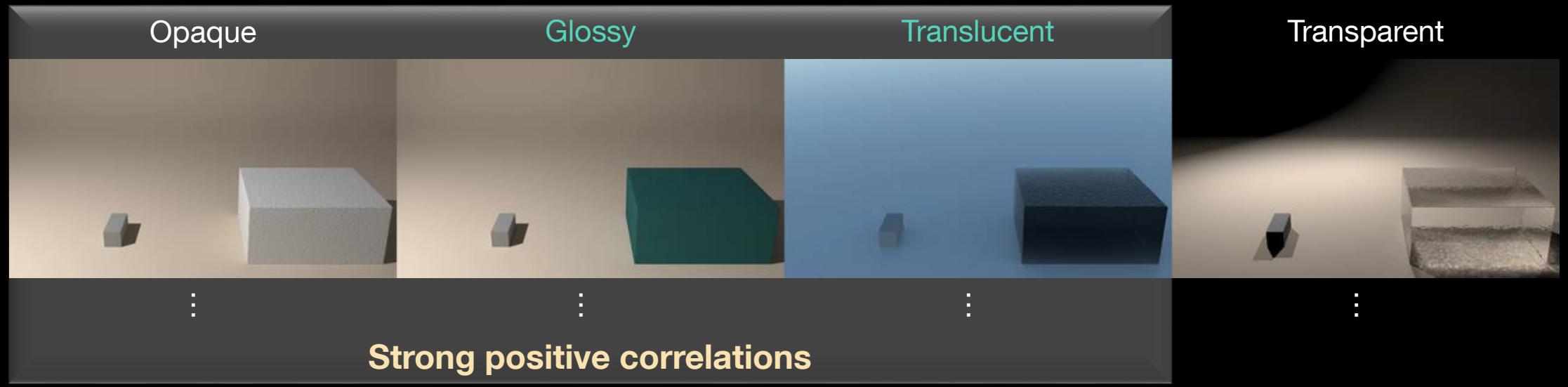
Insights:

- Viewers prefer SPH when comparable resolutions are used
- FLIP & APIC are preferred when the computational resources are limited
- The commonly used factor for particle skinning is confirmed
- For liquids, splashes are important for visual accuracy

Discussion: Subjective Task

Two additional styles: glossy & translucent

- Additional user studies without the reference video



Future Work

Subjective tasks

Other phenomena (e.g., smokes and viscous fluids)

Thank you! Q/A

Further information:

WWW > TUM3D > Publications > 2017 > Perceptual Evaluation of Liquid Simulation Methods

http://ge.in.tum.de/publications/2017-sig-um/