

Simulation in Computer Graphics

Introduction

Matthias Teschner



Graphics Courses

- Key course
 - Image processing and computer graphics (modeling, rendering, simulation)
- Specialization courses
 - Advanced computer graphics (global illumination)
 - Simulation in computer graphics (solids and fluids)
- B.Sc. / M.Sc. project, lab course, B.Sc. / M.Sc. thesis
 - Simulation track, rendering track
 - By appointment per email, semester-aligned

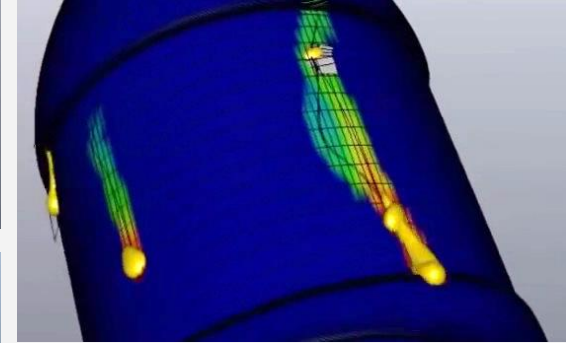
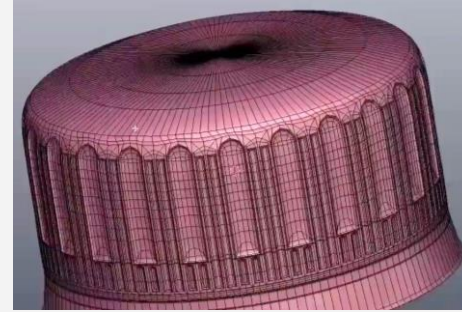
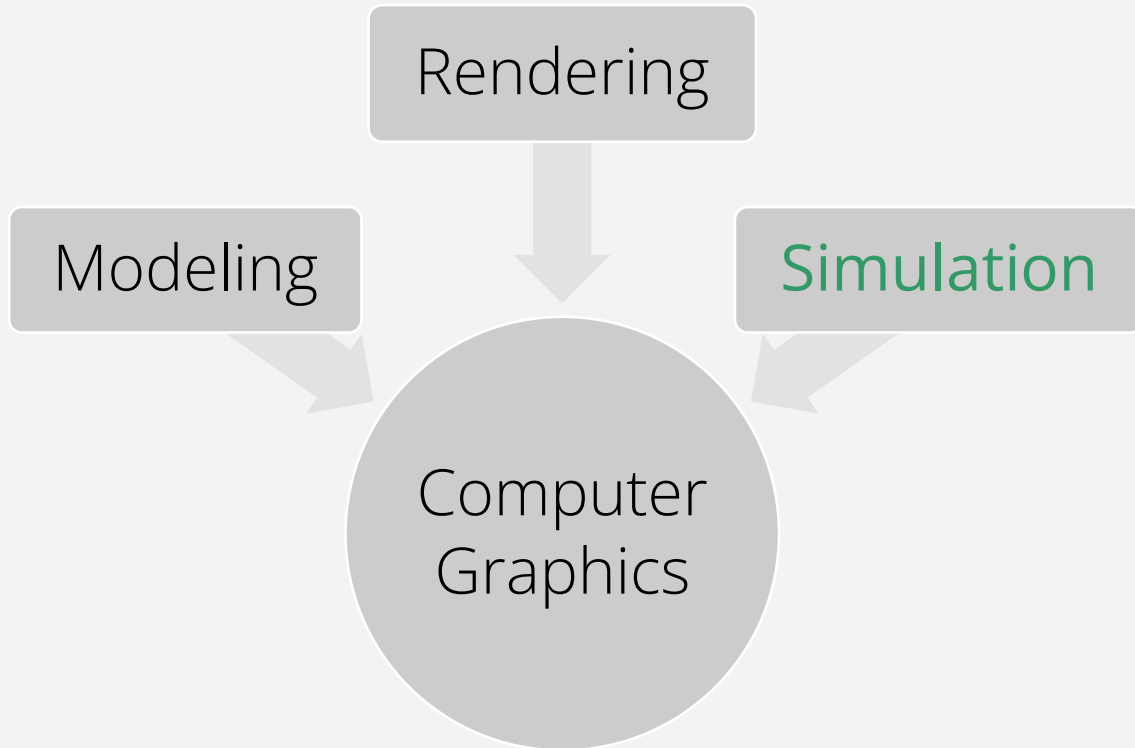
Seminars / Projects / Theses in Graphics

Semester	Simulation Track	Rendering Track
Winter	Simulation Course	
Summer	Key Course Lab Course - Simple fluid solver Simulation Seminar	Key Course Lab Course - Simple Ray Tracer Rendering Seminar
Winter	Master Project - PPE fluid solver Rendering Seminar	Rendering Course Master Project - Monte Carlo RT Simulation Seminar
Summer	Master Thesis Research-oriented topic	Master Thesis Research-oriented topic

Outline

- Motivation
- Topics
- Organization

Computer Graphics



CGMeetup: CGI VFX Breakdown HD "Making of Share a Coke Vfx by ARMA" | CGMeetup. [Youtube]

Course Goals

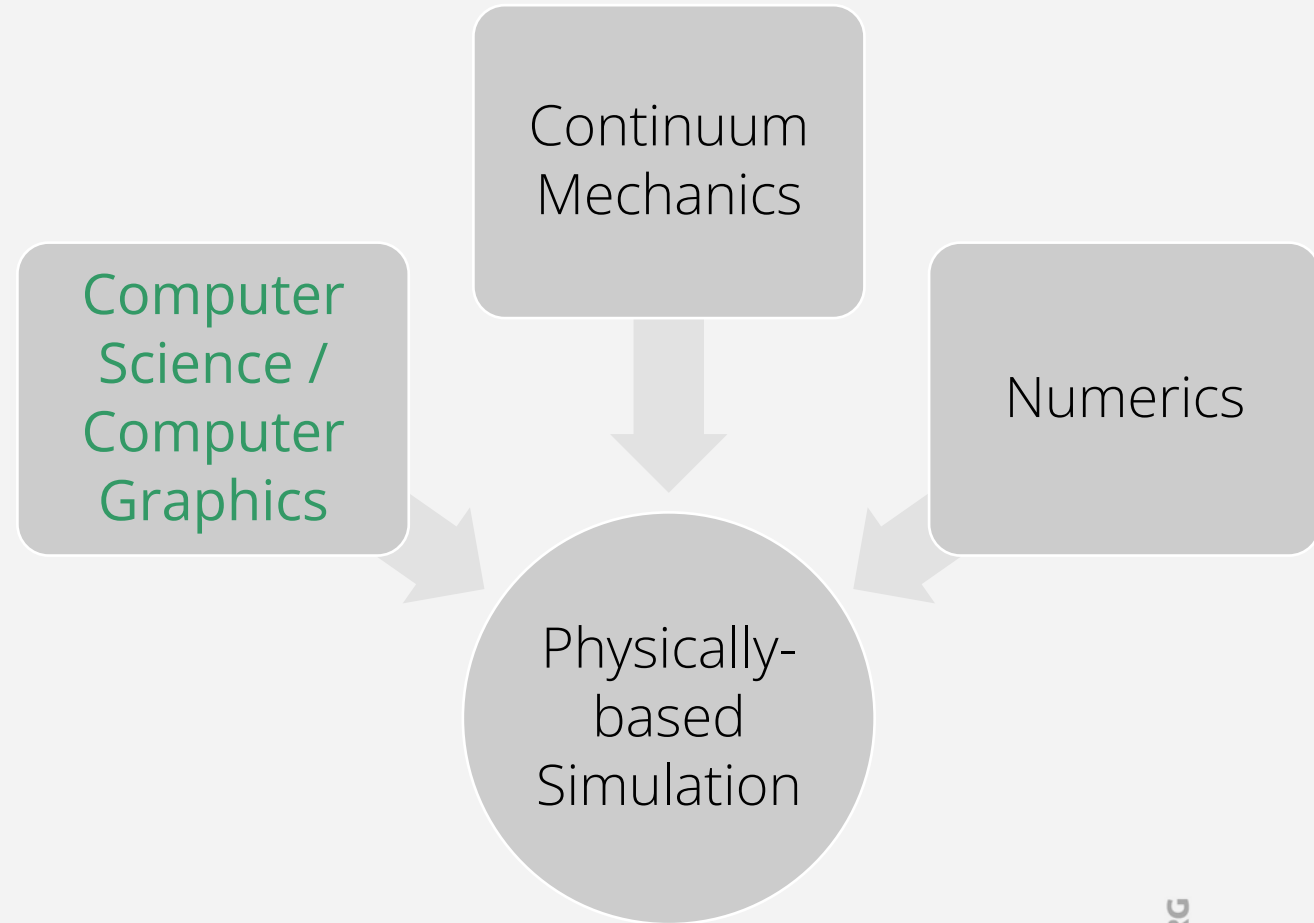
- Physically-based simulation of the dynamics of rigid bodies, deformable objects and fluids



Gissler, Peer, Band,
Bender, Teschner,
ACM Transactions
on Graphics, 2018.

Context

- Efficient and reliable simulation components
- Versatile interplay of simulation components
- Computer science / computer graphics aspects for physically-based simulation

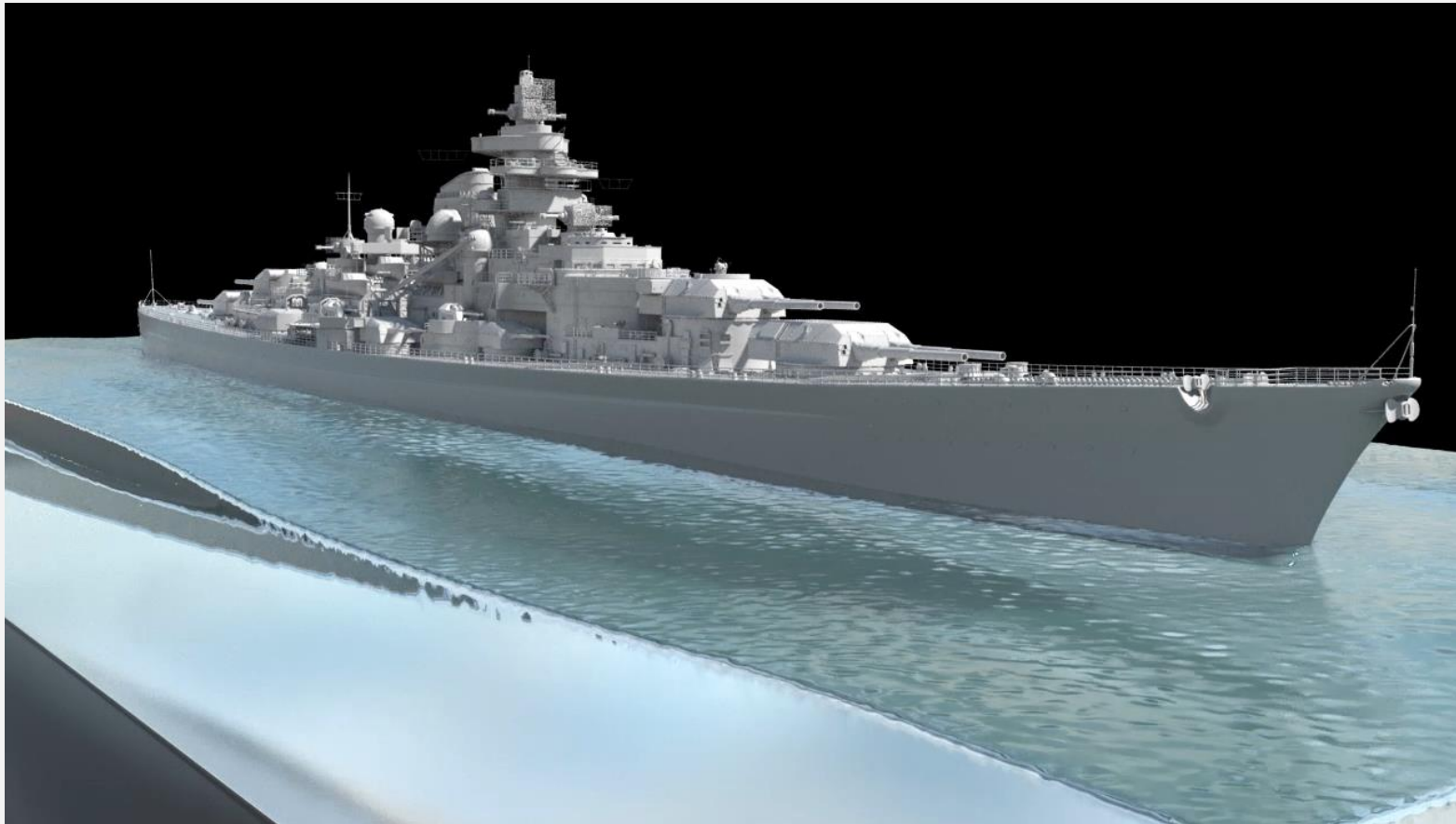


Terminology

- Physically based simulation
- Scientific computing
- Real-time physics
 - Interactive scenarios
- High-performance computing
 - Large scenarios

Applications

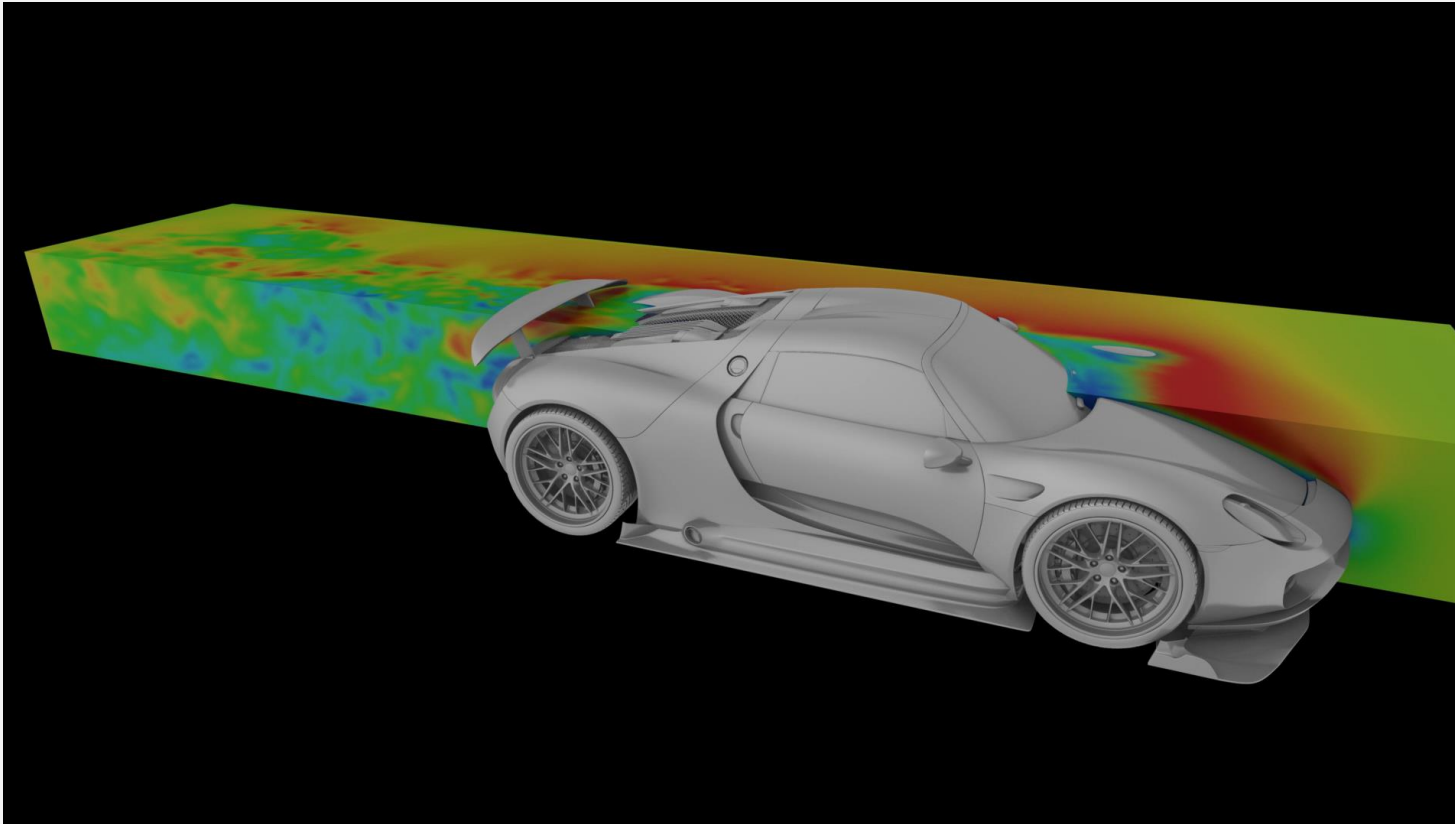
- Visual effects (cooperation with Pixar)



Peer, Ihmsen,
Cornelis, Teschner,
ACM Transactions
on Graphics, 2016.

Applications

- Computer-aided engineering (cooperation with FIFTY2)



Band, Gissler, Teschner,
Computer Graphics
Forum, 2020.

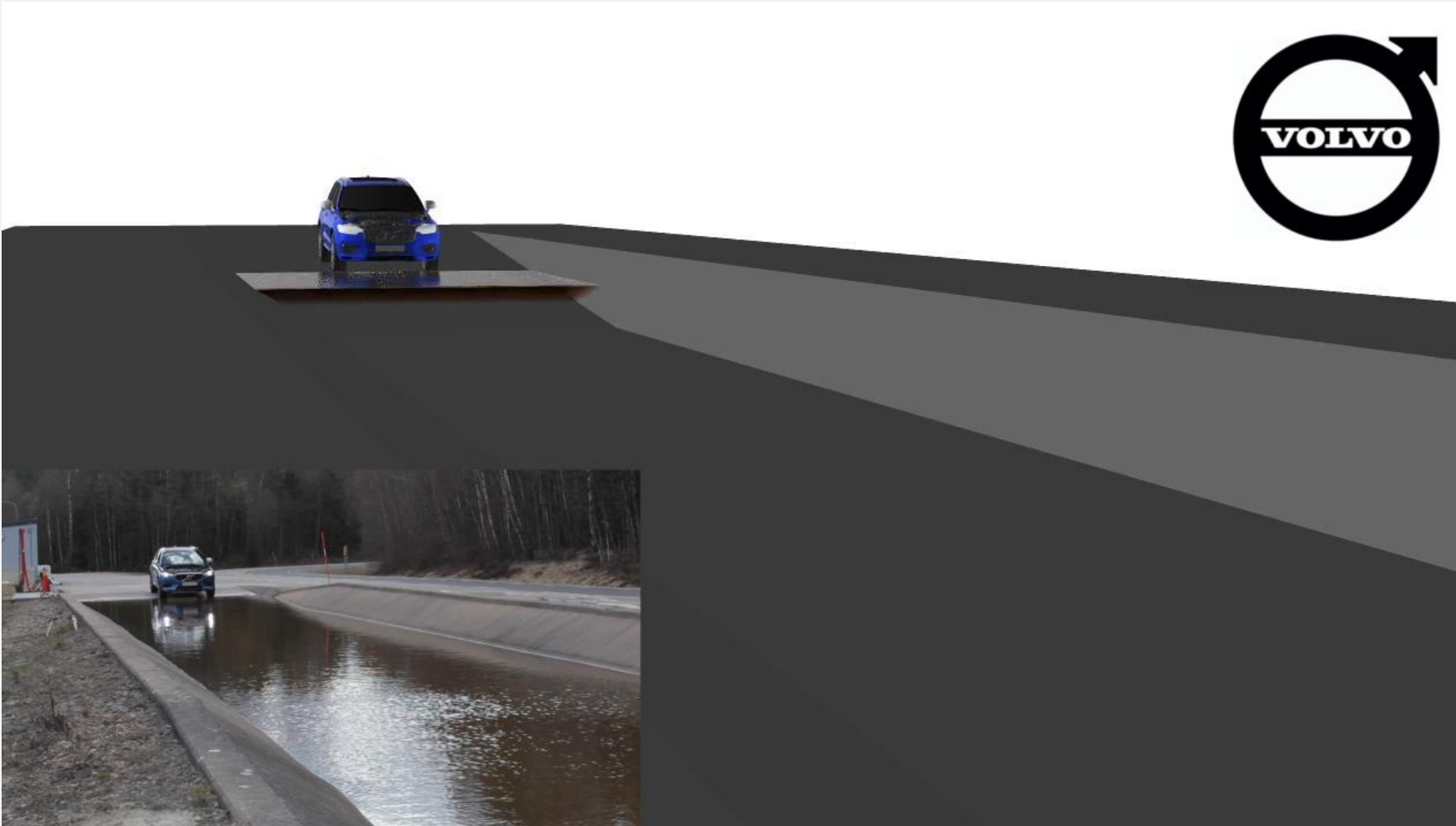
Applications

- FIFTY2 Technology GmbH
 - Spin-off
 - Simulation of fluids and solids (PreonLab)
 - Automotive applications
 - Efficiency, usability, reliability
 - Simulation accuracy and speed, versatile sensors, advanced visualization



FIFTY2 Technology GmbH, AVL, PreonLab 3.1, 2018.

Applications



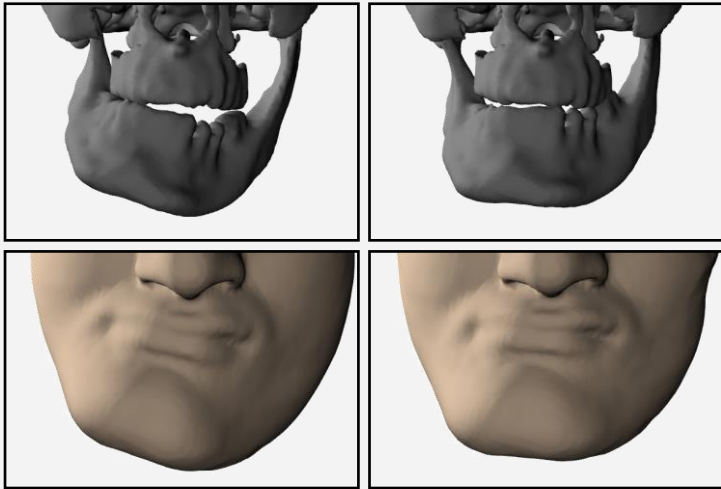
Johan Idoffsson
Chalmers University

Volvo Cars

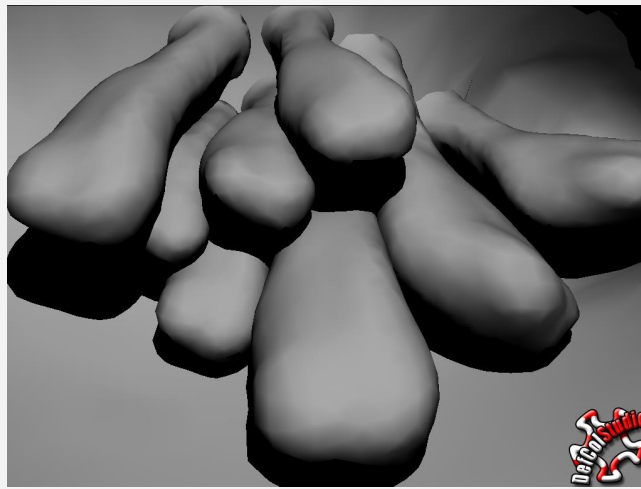
PreonLab
FIFTY2 Technology

Applications

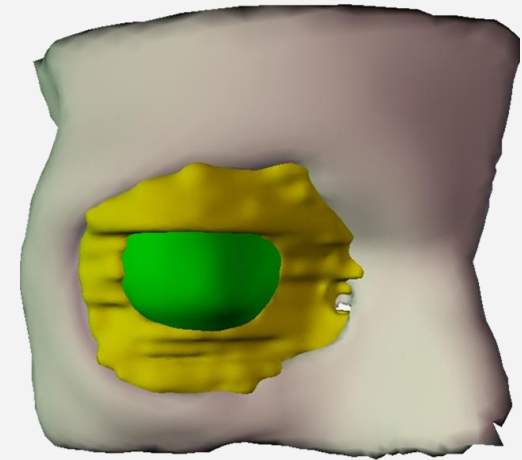
- Computational medicine



Pre-operative planning in cranio-maxillofacial surgery.



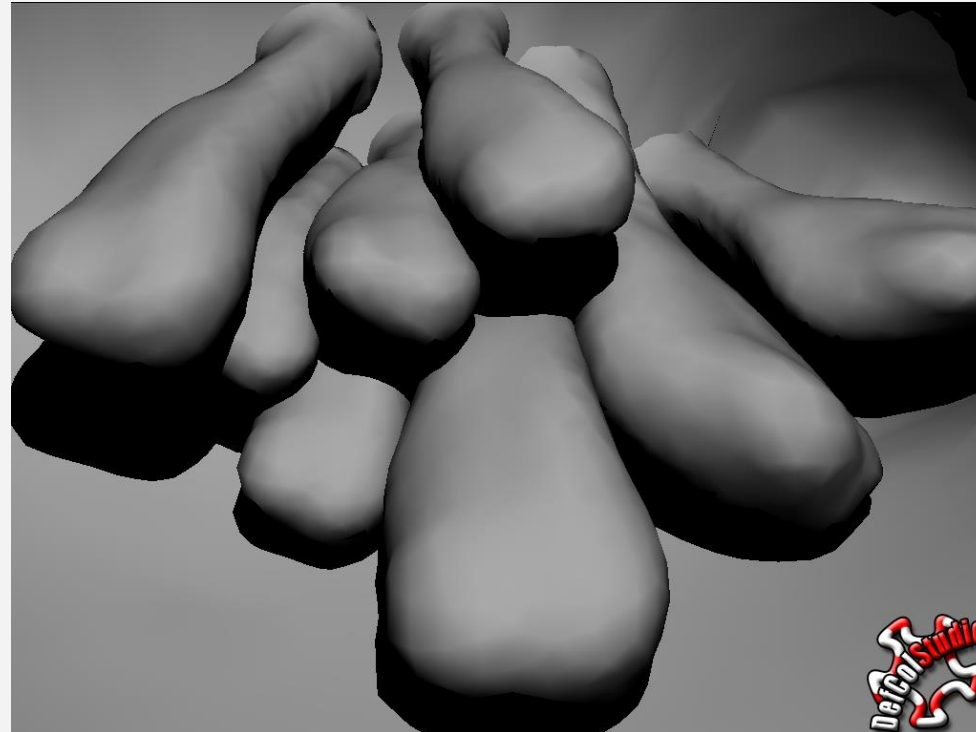
Interactive hysteroscopy simulation for educational purposes.



Intra-operative support in orbital reconstruction.

Applications

- Interactive hysteroscopy simulation



Applications

- Games
 - Havok Physics (Microsoft)
 - PhysX (NVIDIA)
 - CryEngine (Crytek)
 - Blender Physics
 - Pixar, Ubisoft, ...



NVIDIA PhysX

Applications

- Interactive dynamic animations
 - Robust
 - Versatile
- Focus on the interplay of different animation aspects
 - Representations
 - Dynamics
 - Constraints, e.g. collisions



Interacting deformable objects

Outline

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- Topics
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Topics

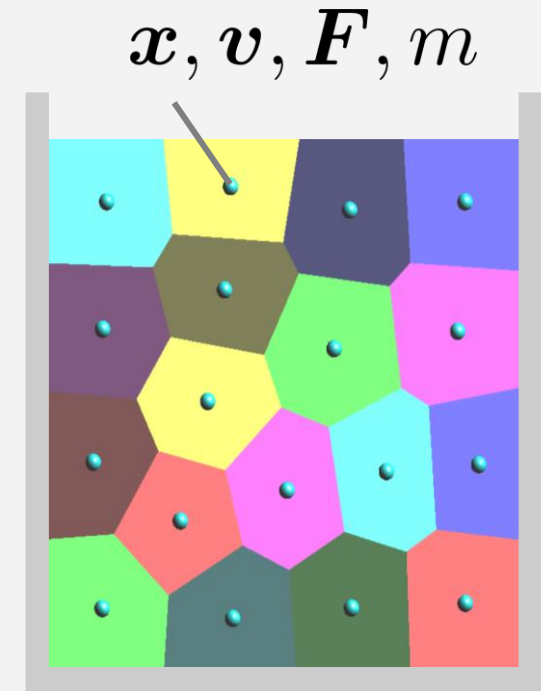
- Particle motion
- Deformable solids
- Fluids
- Rigid bodies
- Collision detection

Particle Motion

- Particles
 - Are small parts of solids and fluids with mass m
 - Move over time t with changing position $\mathbf{x}(t)$ and velocity $\mathbf{v}(t)$ due to forces $\mathbf{F}(t)$
- Motion governed by
$$\mathbf{F}(t) = m \frac{d\mathbf{v}(t)}{dt} \quad \mathbf{v}(t) = \frac{d\mathbf{x}(t)}{dt}$$
- Numerical integration to approximate $\mathbf{x}(t)$ and $\mathbf{v}(t)$

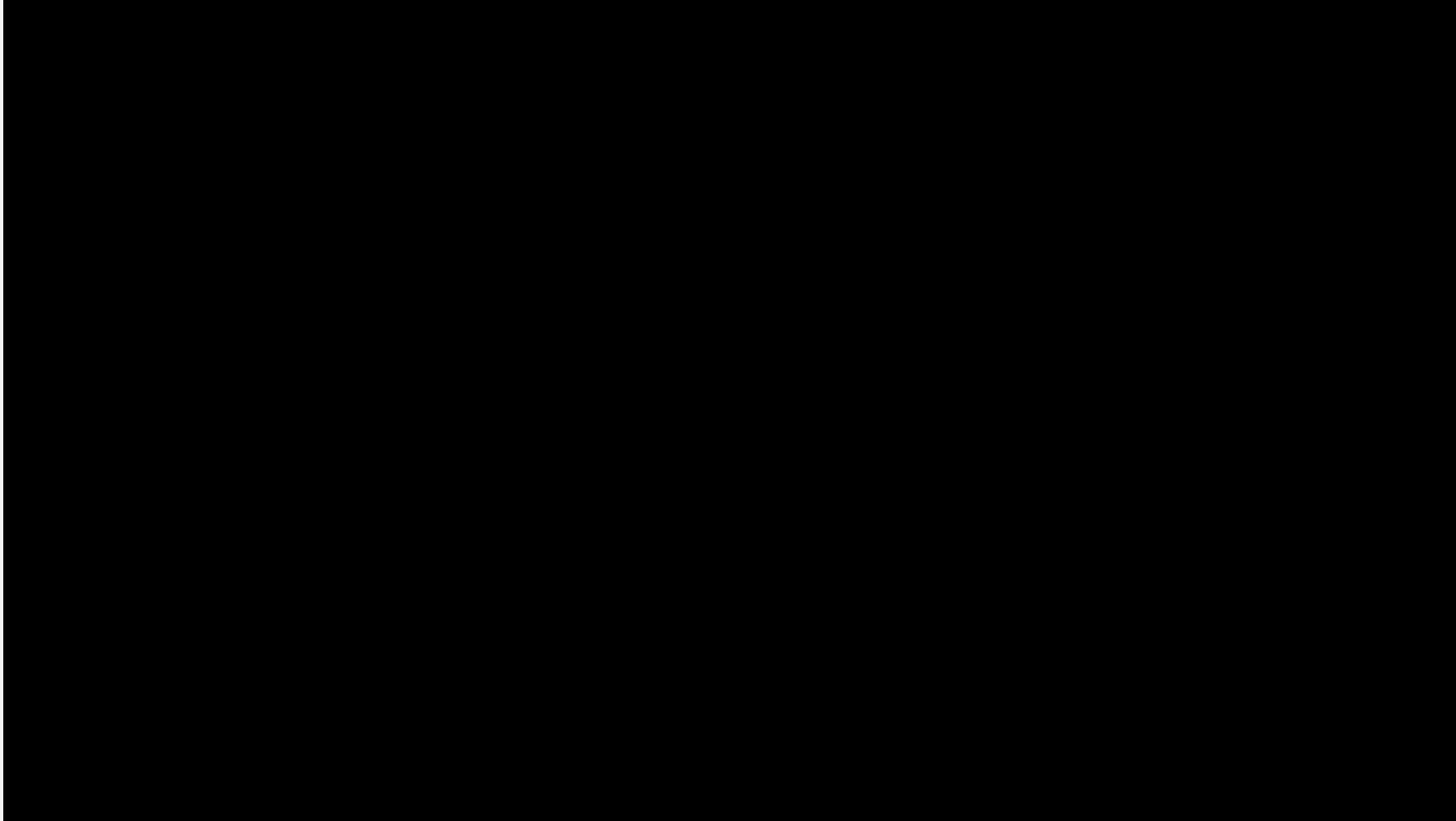


Fluid body



Fluid particles

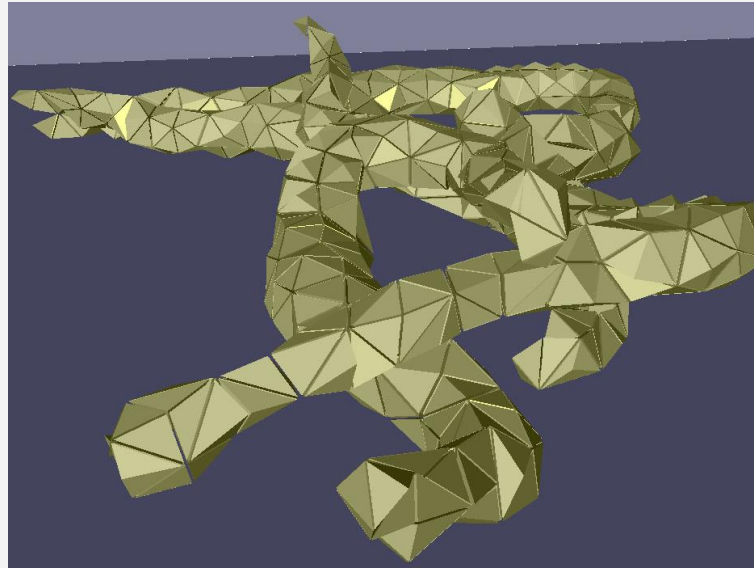
Versatile Materials



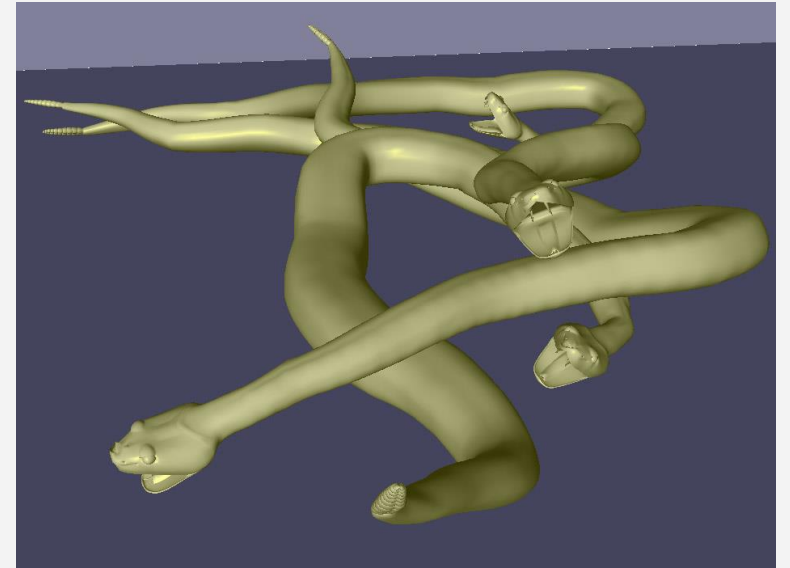
Peer,
Gissler,
Band,
Teschner,
CGF,
2018.

Deformable Solids

- Particle representation
- Displacement
- Strain
- Stress
- Strain energy
- Force



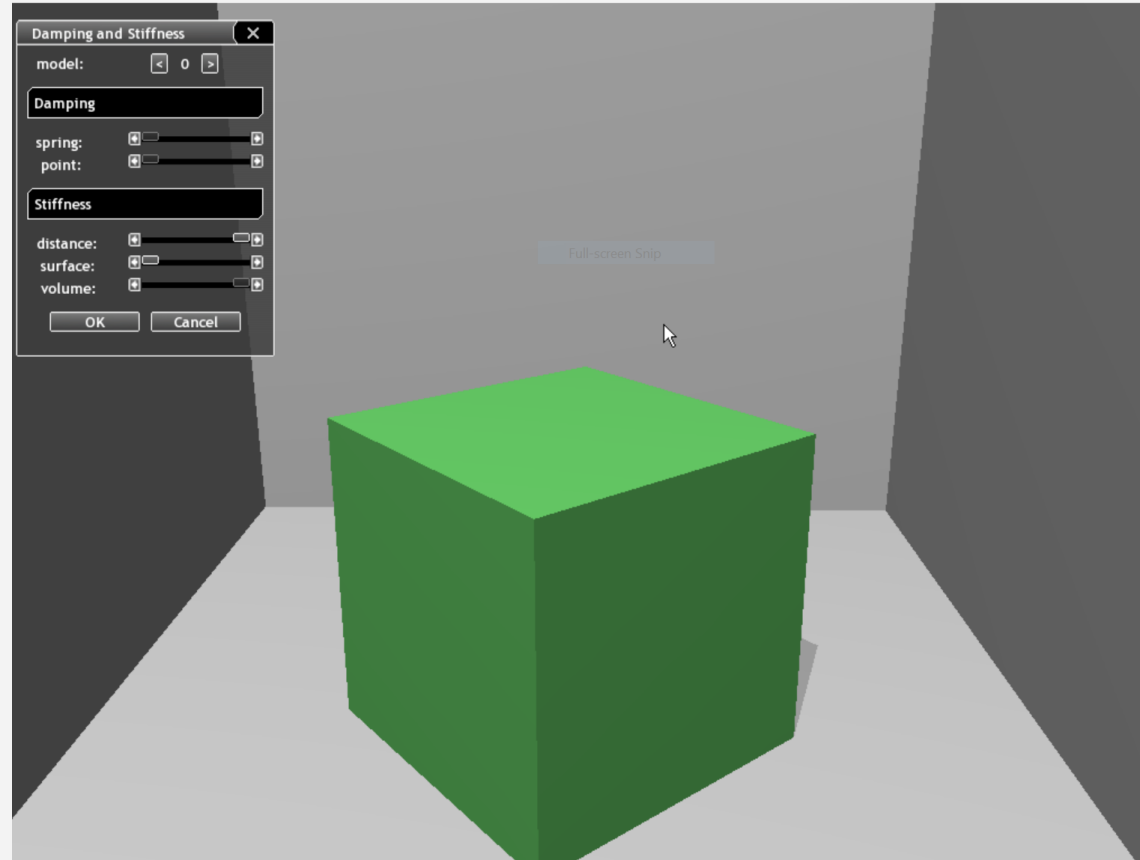
Volumetric mesh



Surface mesh

Deformable Solids

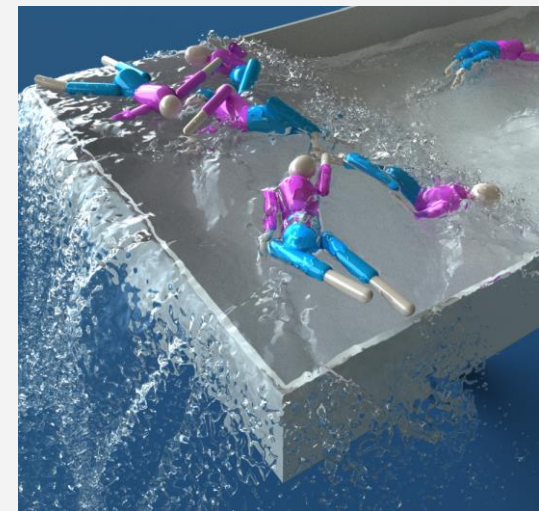
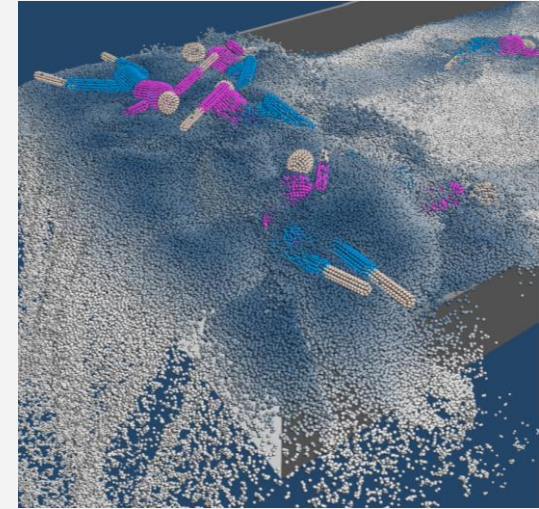
- Example forces
 - Distance preservation
 - Volume preservation
 - Surface tension



Fluids

- Fluid is subdivided into particles
- Fluid solvers compute velocities $\mathbf{v}(t)$ over time t
- Lagrangian fluid solvers advect particle positions $\mathbf{x}(t)$ with their velocity $\mathbf{v}(t)$
- Velocity changes are computed from the Navier-Stokes equation

$$\frac{d\mathbf{v}(t)}{dt} = -\frac{1}{\rho}\nabla p(t) + \nu\nabla^2\mathbf{v}(t) + \frac{\mathbf{F}(t)}{m}$$

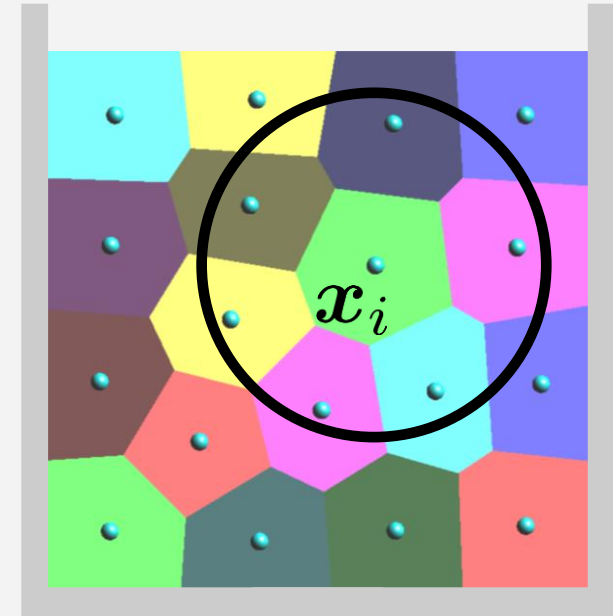


Akinci,
Ihmsen,
Akinci,
Solenthaler,
Teschner,
ACM TOG,
2012.

Fluids

- Velocity change at particle \mathbf{x}_i is computed as sum over adjacent particles \mathbf{x}_j
- E.g., acceleration due to pressure gradient, i.e. density differences

$$-\frac{1}{\rho_i} \nabla p_i(t) = -\sum_j m_j \left(\frac{p_i}{\rho_i^2} + \frac{p_j}{\rho_j^2} \right) \nabla W_{ij}$$



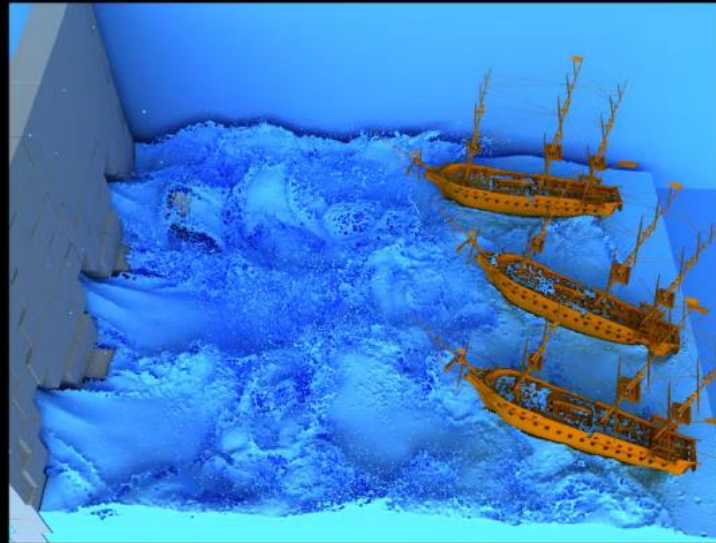
Fluids

- Key tasks
 - Neighbor search
 - For each particle, find adjacent particles within a certain distance
 - Required for the computation of particle accelerations
 - Spatial data structures: space subdivision, bounding volume hierarchies
 - Pressure computation
 - Solve a pressure Poisson equation
$$\Delta t \nabla^2 p_i = \frac{1}{\Delta t} (\rho_0 - \rho_i^*) \Rightarrow \mathbf{A} \mathbf{p} = \mathbf{s}$$
 - Required for volume preservation / zero velocity divergence

Fluids

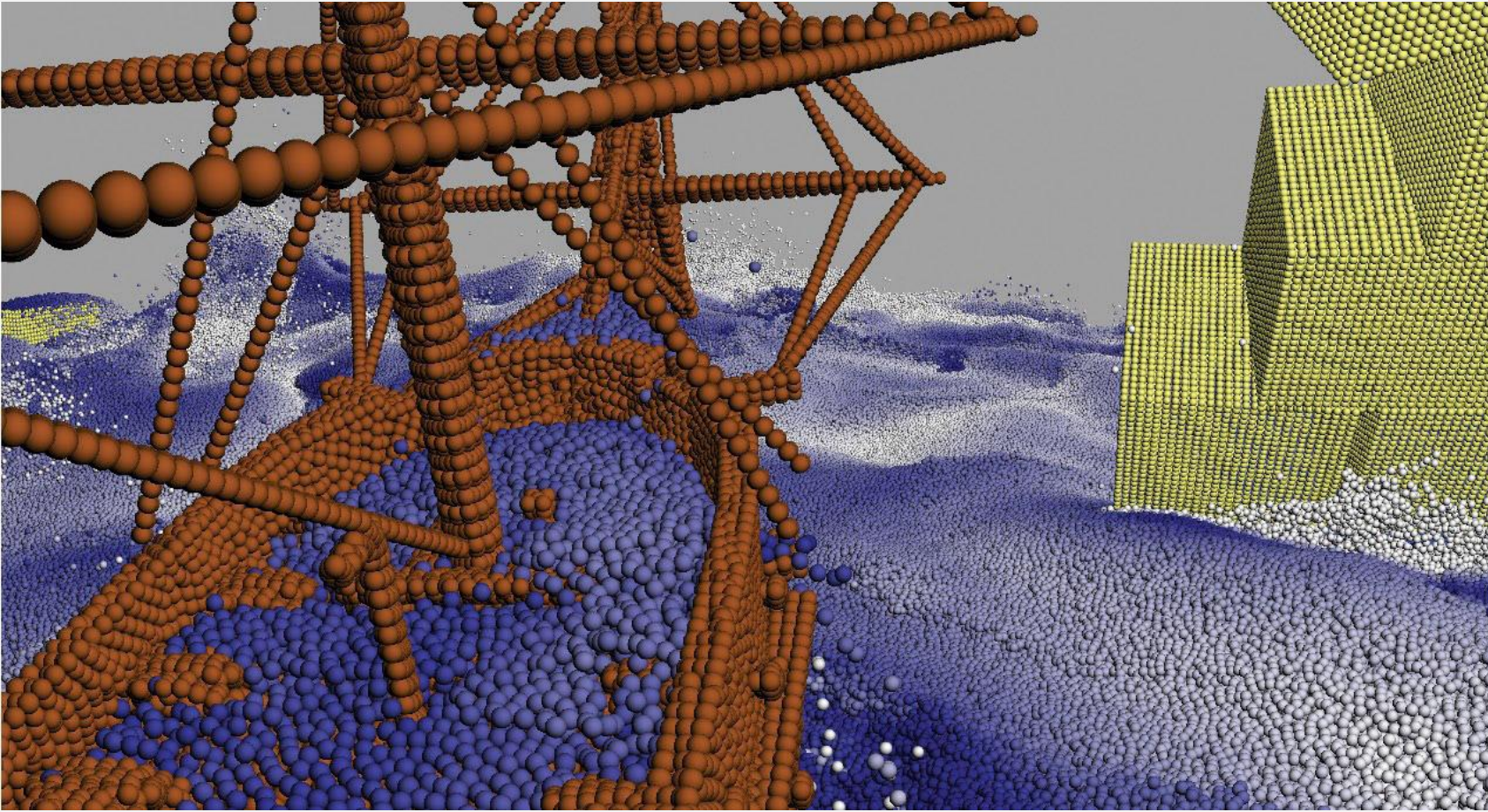
Dam break

20M fluid particles



Akinci, Ihmsen,
Akinci, Solenthaler,
Teschner,
ACM Transactions
on Graphics, 2012.

Fluids



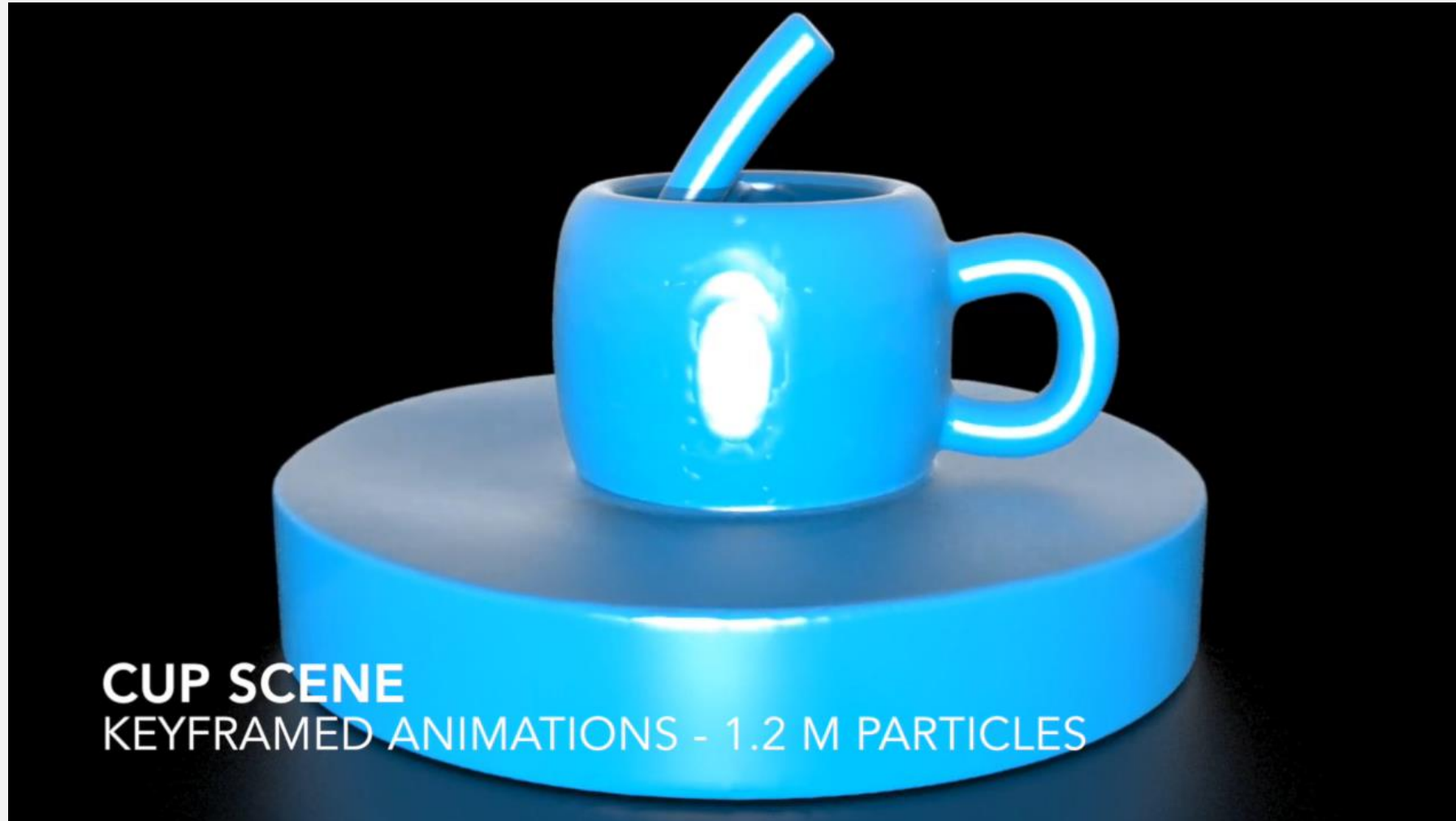
Fluids



Ihmsen, Cornelis,
Solenthaler,
Horvath, Teschner,
IEEE TVCG, 2014.

FIFTY2, PreonLab.

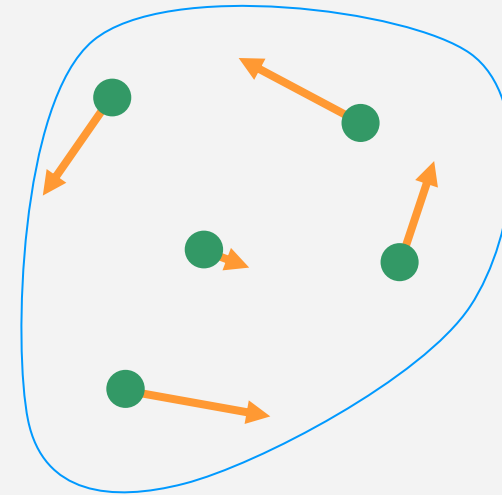
Fluids



Cornelis, Ihmsen,
Peer, Teschner,
Computers &
Graphics, 2017.

Rigid Bodies

- Particles connected by springs with infinite stiffness
- Entire body described by one position and one orientation
- Forces at particles cause translation and rotation of the entire body
- Mass distribution, orientation, angular velocity, torque

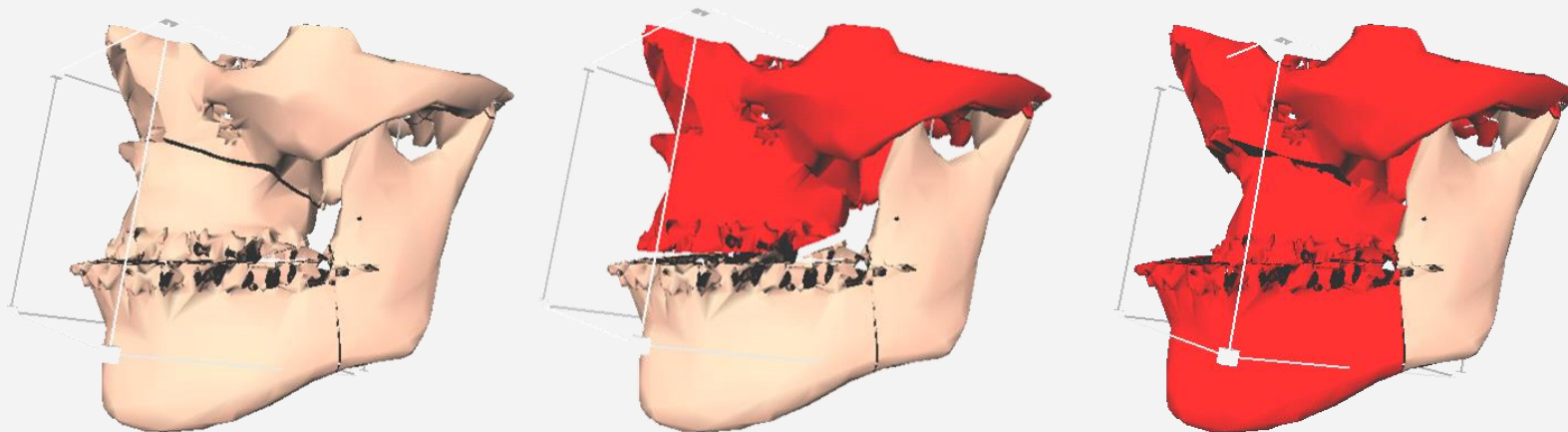


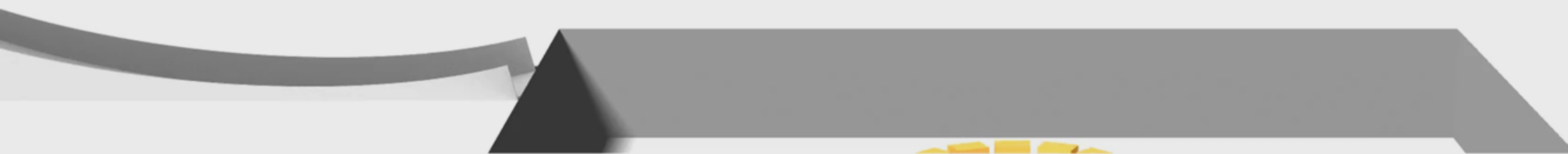
Topics

- Particle motion
- Deformable solids
- Fluids
- Rigid bodies
- Collision detection

Collision Detection

- Detecting interferences of objects
- Avoid time-consuming primitive-primitive handling
- Bounding volumes, space subdivision, distance fields
- Various implementations





Outline

- Motivation
- Topics
- Organization

Tentative Course Syllabus

- Particle motion
 - Position and velocity computation (ODE)
- Deformable solids
 - Force computation (Energy minimization, FEM)
- Fluids
 - Force computation (mainly SPH)
- Rigid bodies
- Collision detection
 - Spatial data structures

Exercises / Exam

- Exercises
 - Voluntary
- Exam
 - Written
 - Based on slide sets
 - Relevant material will be summarized
 - Text exam on our web page

Announcement

- Monday, 10:15, Advanced Computer Graphics
- Tuesday, 12:15, Simulation in Computer Graphics
- Wednesday, 10:15, Rendering Seminar
- Wednesday, 12:15, Animation Seminar
- Thursday, 10:15, Proseminar Graphik
- Monday, Oct 28, 14:15, Simulation Tutorial
- Monday, Oct 28, 16:15, Rendering Tutorial
- No tutorials next week

Acknowledgements

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