Simulation in Computer Graphics
Introduction

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Course Information

- Key course
  - Pattern recognition and computer graphics (modeling, rendering, animation)
- Specialization courses
  - Advanced computer graphics (global illumination)
  - Simulation in computer graphics (deformable and rigid solids, fluids)
- Master project, lab course, Master thesis
  - Simulation track, rendering track

Seminars / Projects / Theses in Graphics

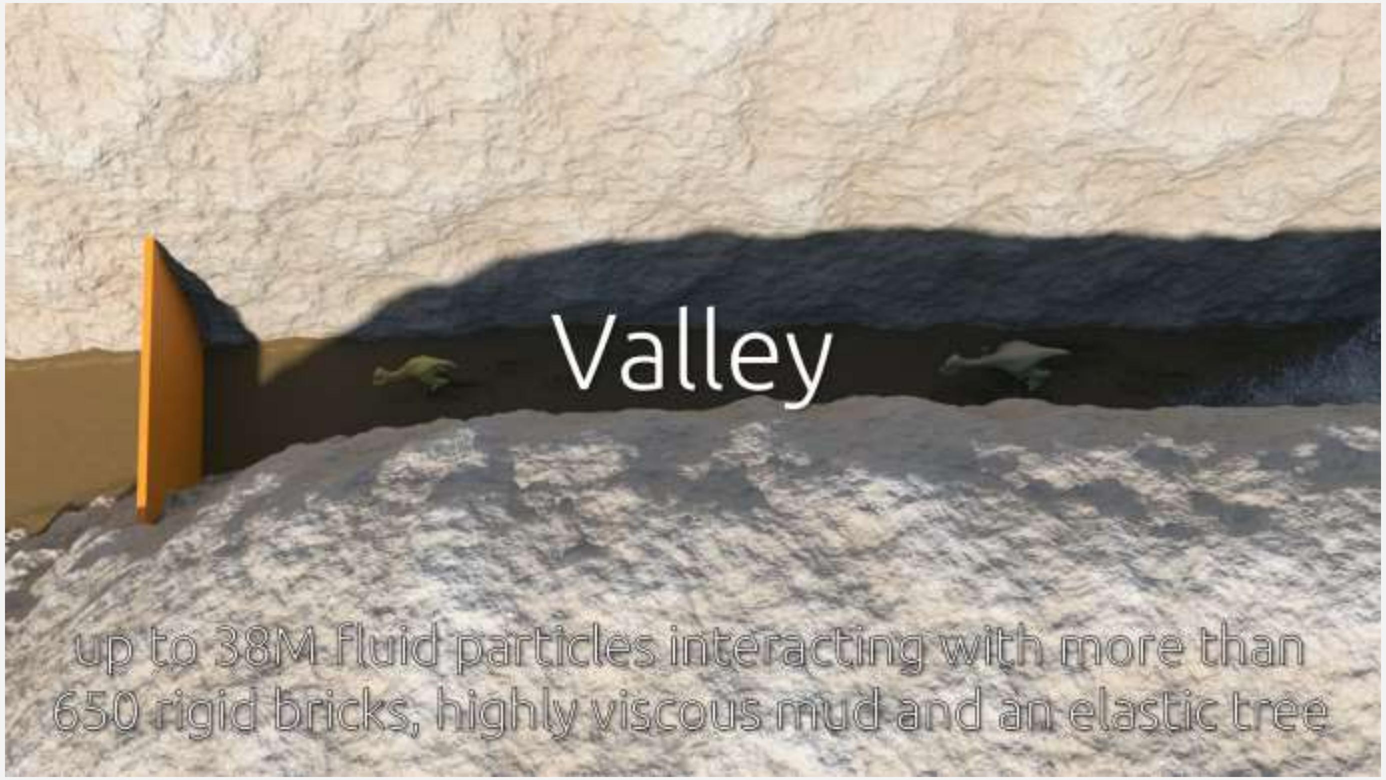
Semester	Simulation Track	Rendering Track
Winter	Key Course Simulation Course	Key Course
Summer	Lab Course - Simple fluid solver Simulation Seminar	Rendering Course Lab Course - Simple raytracer
Winter	Master Project - PPE fluid solver	Master Project - Monte Carlo raytracer Rendering Seminar
Summer	Master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

Outline

- Motivation
- Topics
- Organization

Course Goals

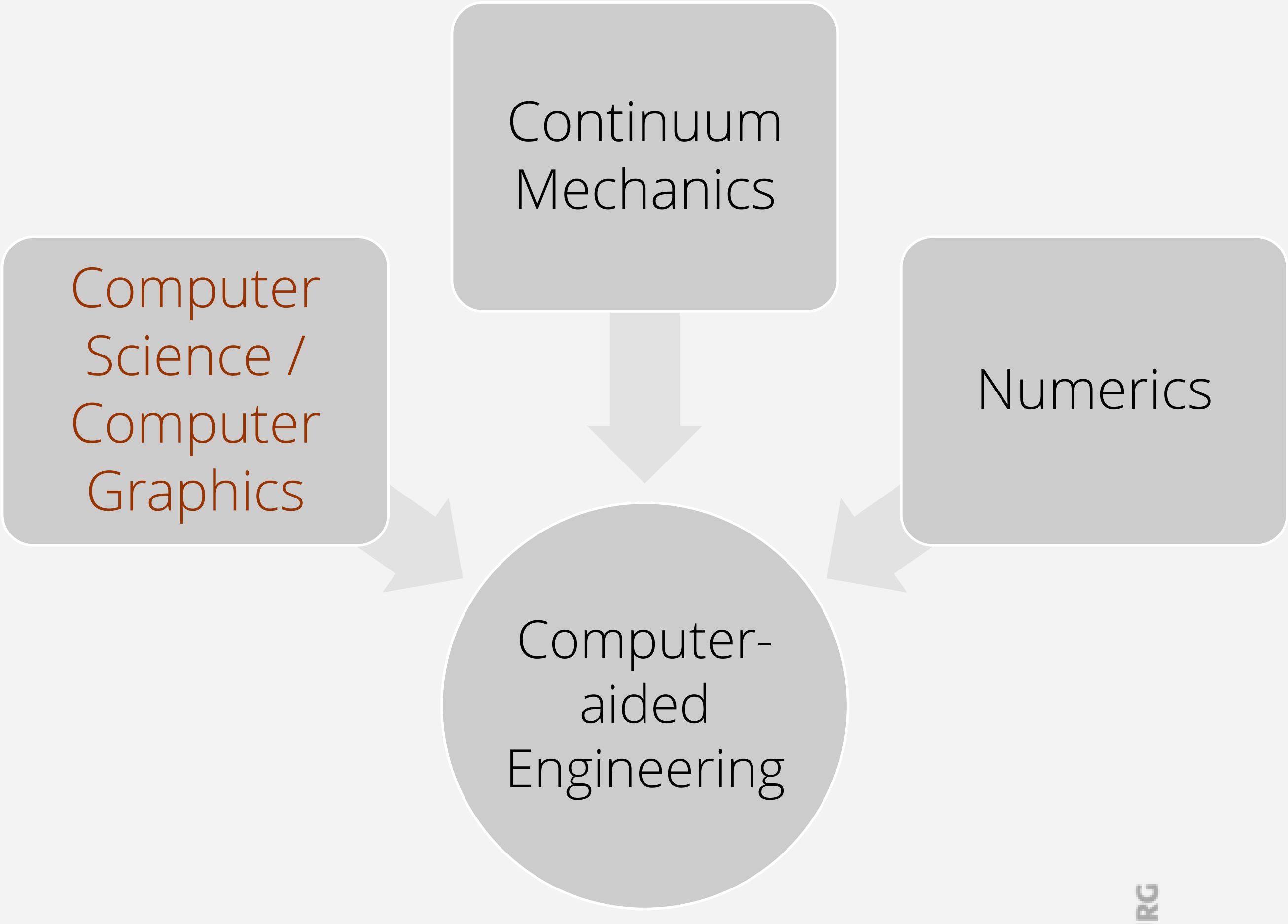
– Physically-based simulation of the dynamics of rigid bodies, deformable objects and fluids



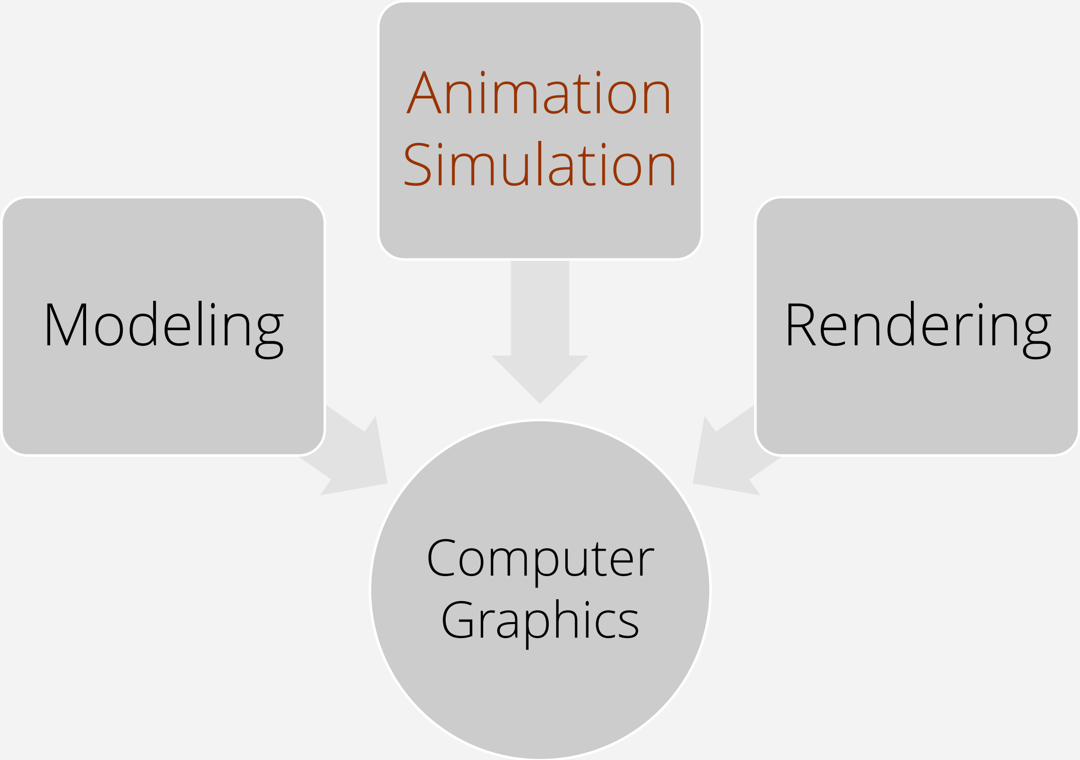
Gissler, Peer, Band, Bender, Teschner, ACM Transactions on Graphics, 2018.

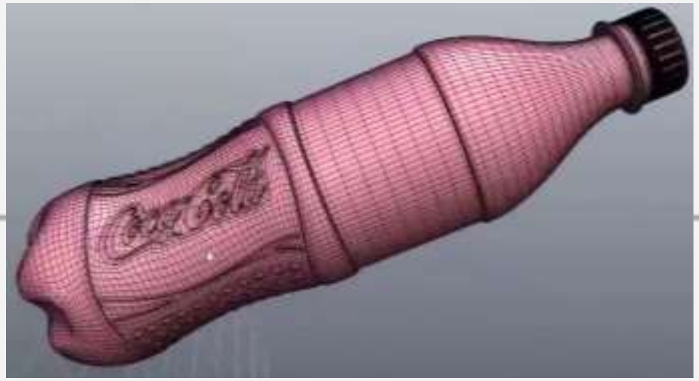
Course Goals

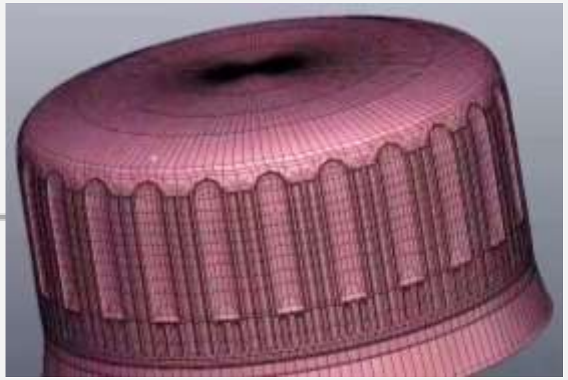
- Computer science / computer graphics aspects for computer-aided engineering
- Efficient and reliable simulation components
- Versatile interplay of simulation components

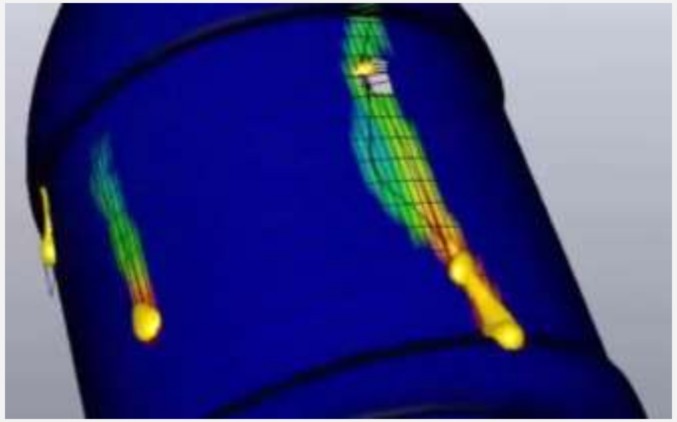


Context





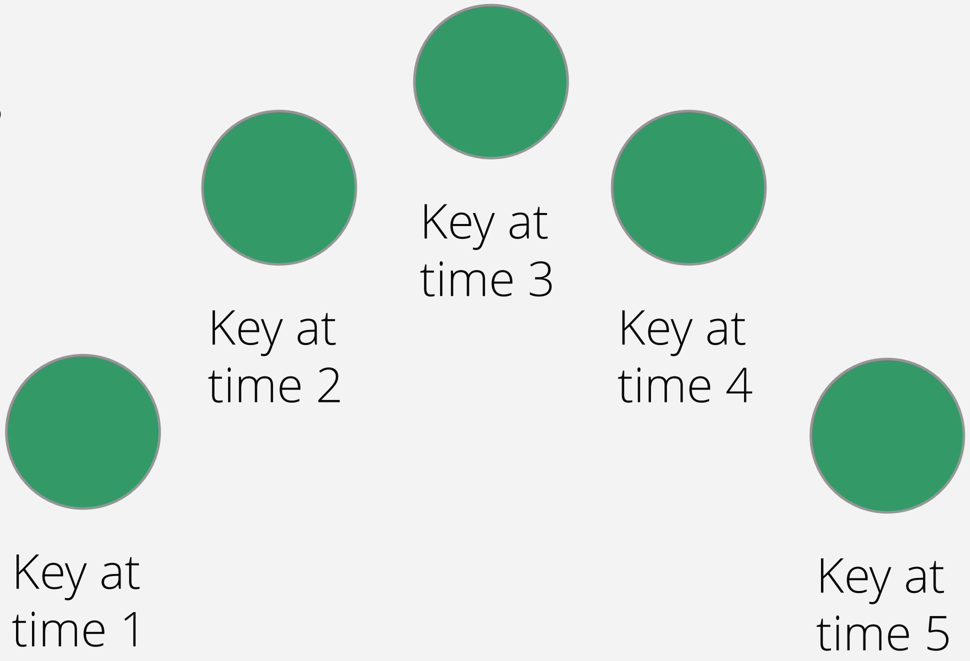




CGI Making of
Share a Coke VFX
Breakdown by ARMA.

Keyframe vs. Physically-based Animation

- Keyframe animation
  - Interpolation between keyframes
  - Fully controllable
  - Predefined, non-interactive
- Physically-based animation
  - Driven by physical laws
  - Interactive



Computer-Aided Engineering vs. Physically-based Animation

- Computer-aided engineering
  - Focus on accuracy, substitute of real experiments
- Physically-based animation
  - Focus on accuracy and performance
  - For games: as accurate as possible considering speed and stability constraints
  - For engineering: as fast as possible considering accuracy constraints
  - Focus on data structures and algorithms

Applications

– Visual effects (cooperation with Pixar)

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

Applications

– Computer-aided engineering (cooperation with FIFTY2)

FIFTY2 Technology GmbH, PreonLab, 2016.

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Applications

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

FIFTY2 Technology GmbH, AVL, PreonLab 3.1, 2018.

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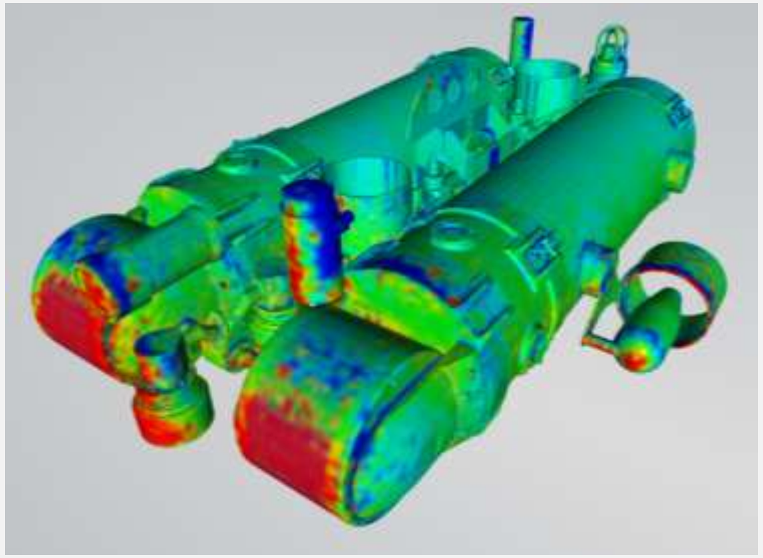
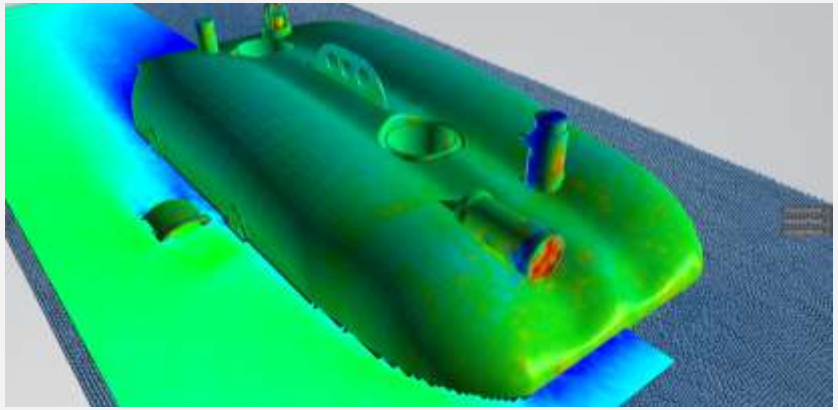
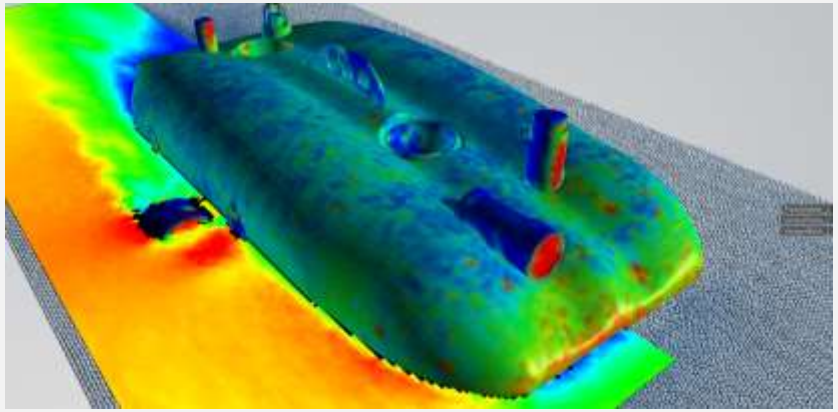
Applications

– Computer-aided engineering (coop. with DFKI Bremen)







FIFTY2 Technology GmbH, PreonLab, 2018.

Applications

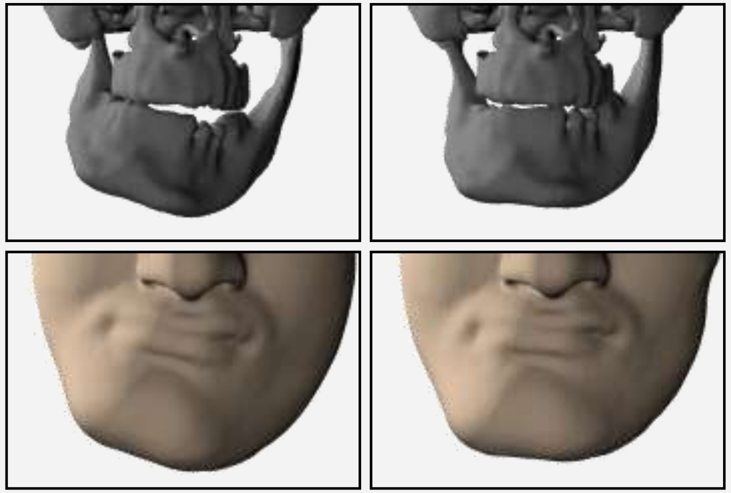
– Art (cooperation with Studio Claudia Comte)

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

Studio Claudia Comte.

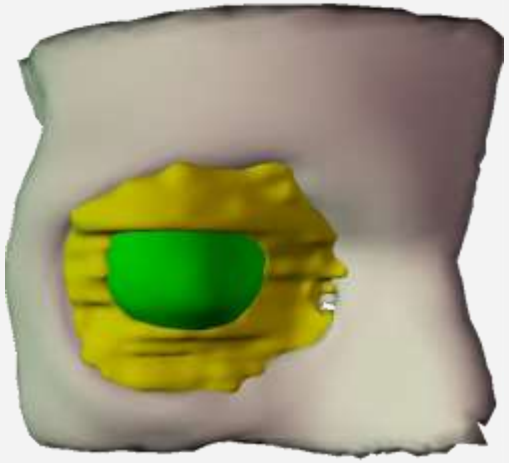
Applications

– Computational medicine



Pre-operative planning in cranio-maxillofacial surgery.

Interactive hysteroscopy simulation for educational purposes.



Intra-operative support in orbital reconstruction.

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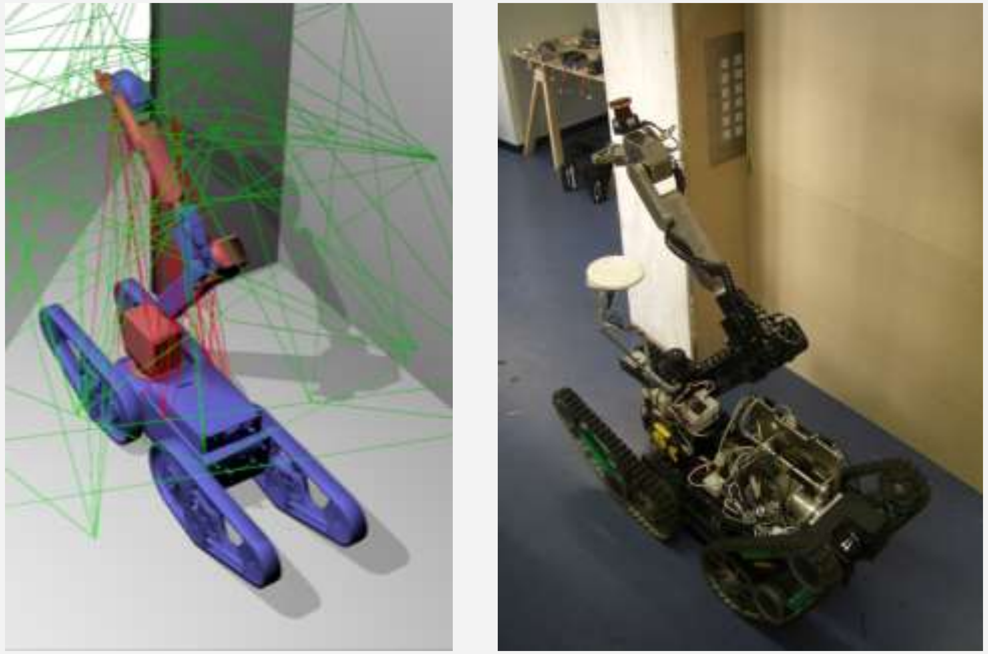
Applications

– Robotics

Support of robot navigation
in environments with
deformable objects



Acceleration of robot navigation
with simulation environments

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Applications

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

NVIDIA PhysX

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Applications

- Interactive dynamic animations
  - Robust
  - Versatile
- Focus on the interplay of different animation aspects
  - Model generation
  - Dynamics
  - Collision handling
  - Constraints

Interacting deformable objects

Outline

- Motivation
- Topics
- Organization

Topics

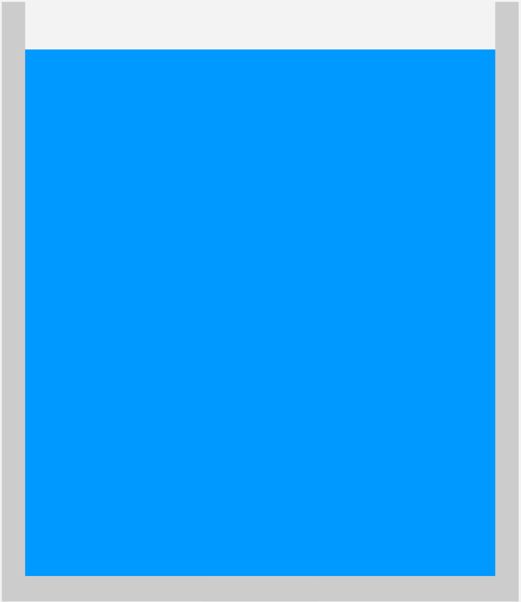
- Particle motion
- Deformable solids
- Fluids
- Rigid bodies
- Collision detection

Particle Motion

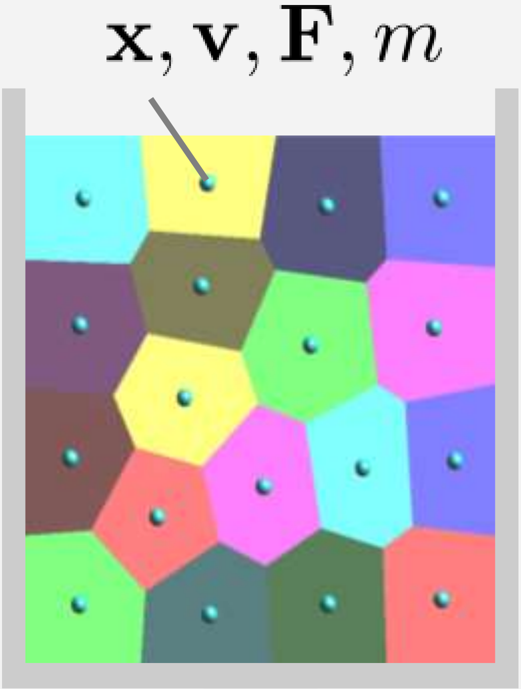
- Particles
  - Are small parts of solids and fluids with mass m
  - Move over time t with changing position $\mathbf{x}(t)$ and velocity $\mathbf{v}(t)$ due to forces $\mathbf{F}(t)$
- Motion governed by

$$\mathbf{F}(t) = m\frac{\mathrm{d}\mathbf{v}(t)}{\mathrm{d}t} = m\frac{\mathrm{d}^2\mathbf{x}(t)}{\mathrm{d}t^2}$$

- Numerical integration to approximate $\mathbf{x}(t)$ and $\mathbf{v}(t)$



Fluid body



Fluid particles

Particle Systems

– Particle sets can be used to mimic dynamic effects

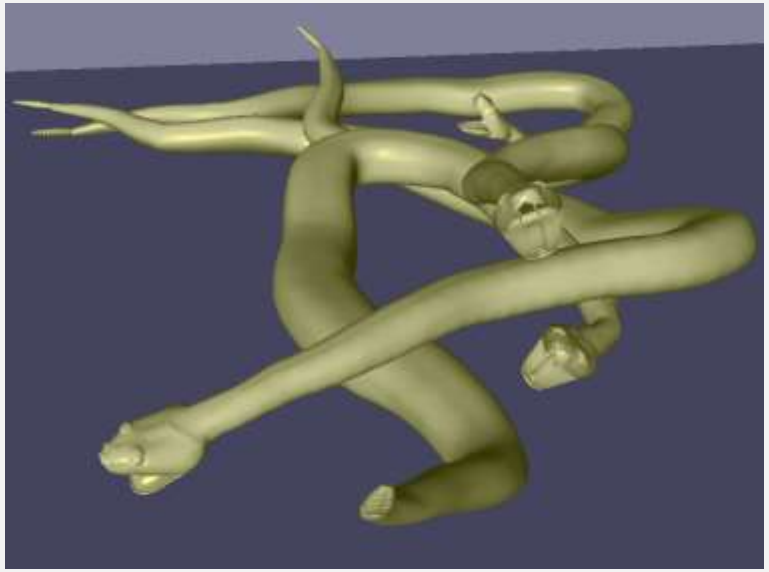
Snow

Fire

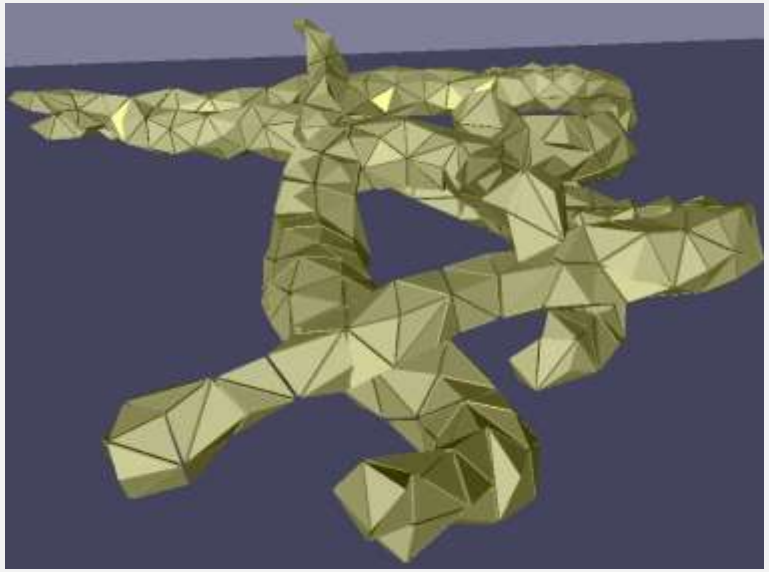
Smoke

Deformable Solids

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



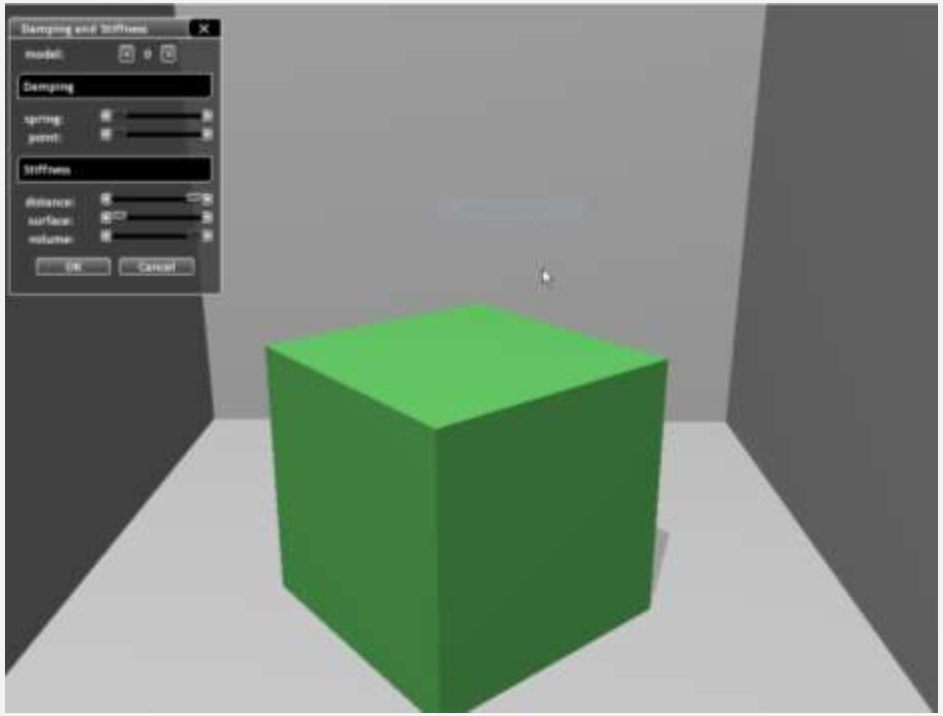
Deformable solid



Approximate tetrahedral mesh

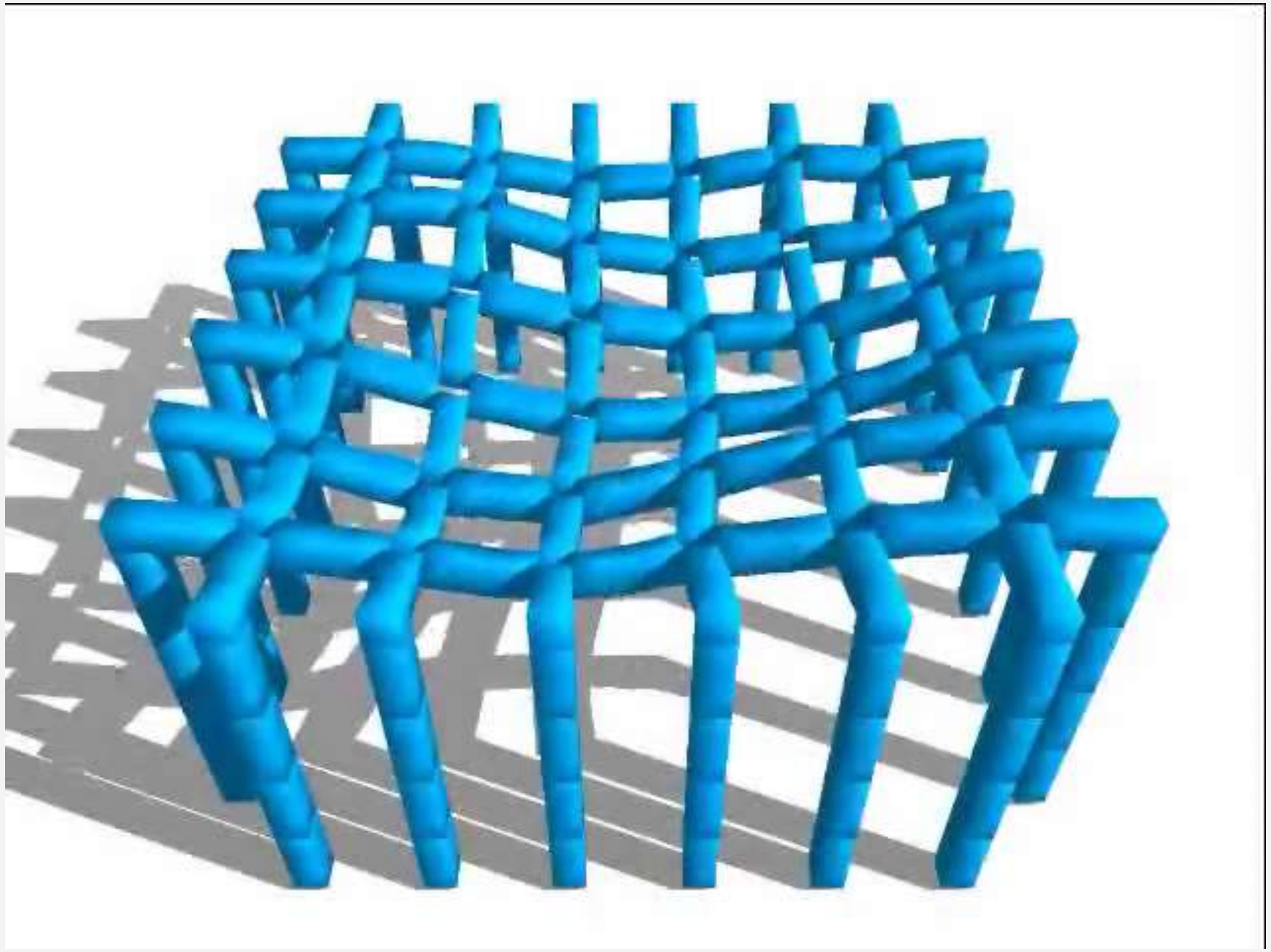
Deformable Solids

- Example forces
  - Distance preservation
  - Volume preservation
  - Surface tension
- Forces from strain energy
- Finite element modeling



Geometric Constraints

- Constrained particle motion
  - Keep a mass point at a position
  - Force a point onto a curve or surface

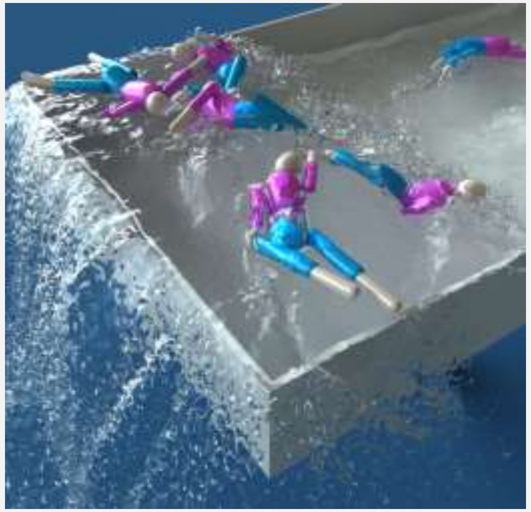


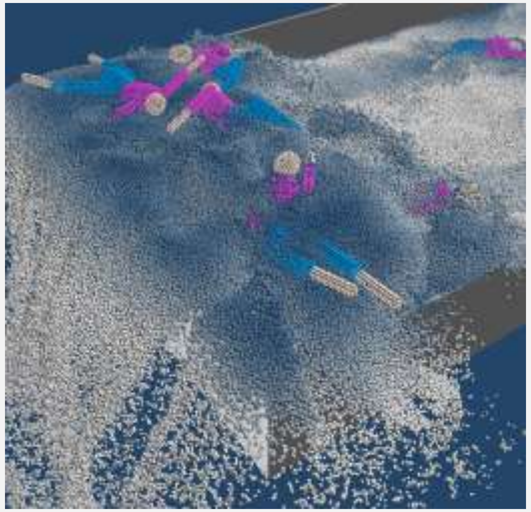
Gissler, Becker, Teschner, VRIPHYS 2007.

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

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



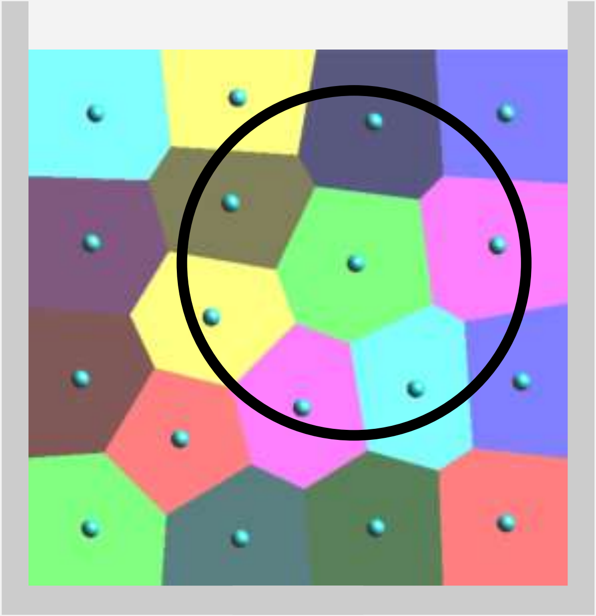


Akinci, Ihmsen, Akinci, Solenthaler, Teschner, ACM TOG, 2012.

Fluids

- Velocity change at particle is computed as sum over i adjacent particles 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

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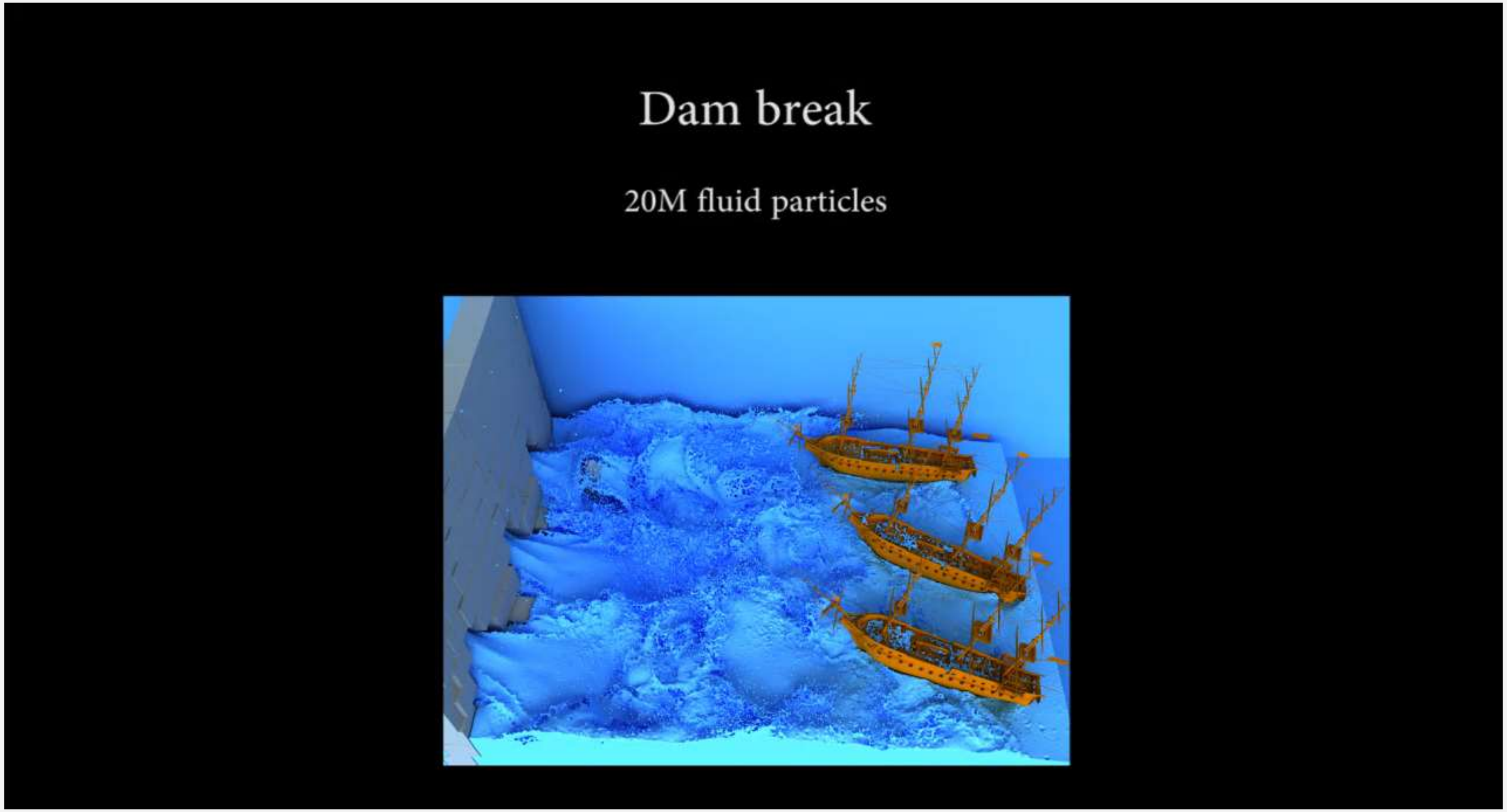
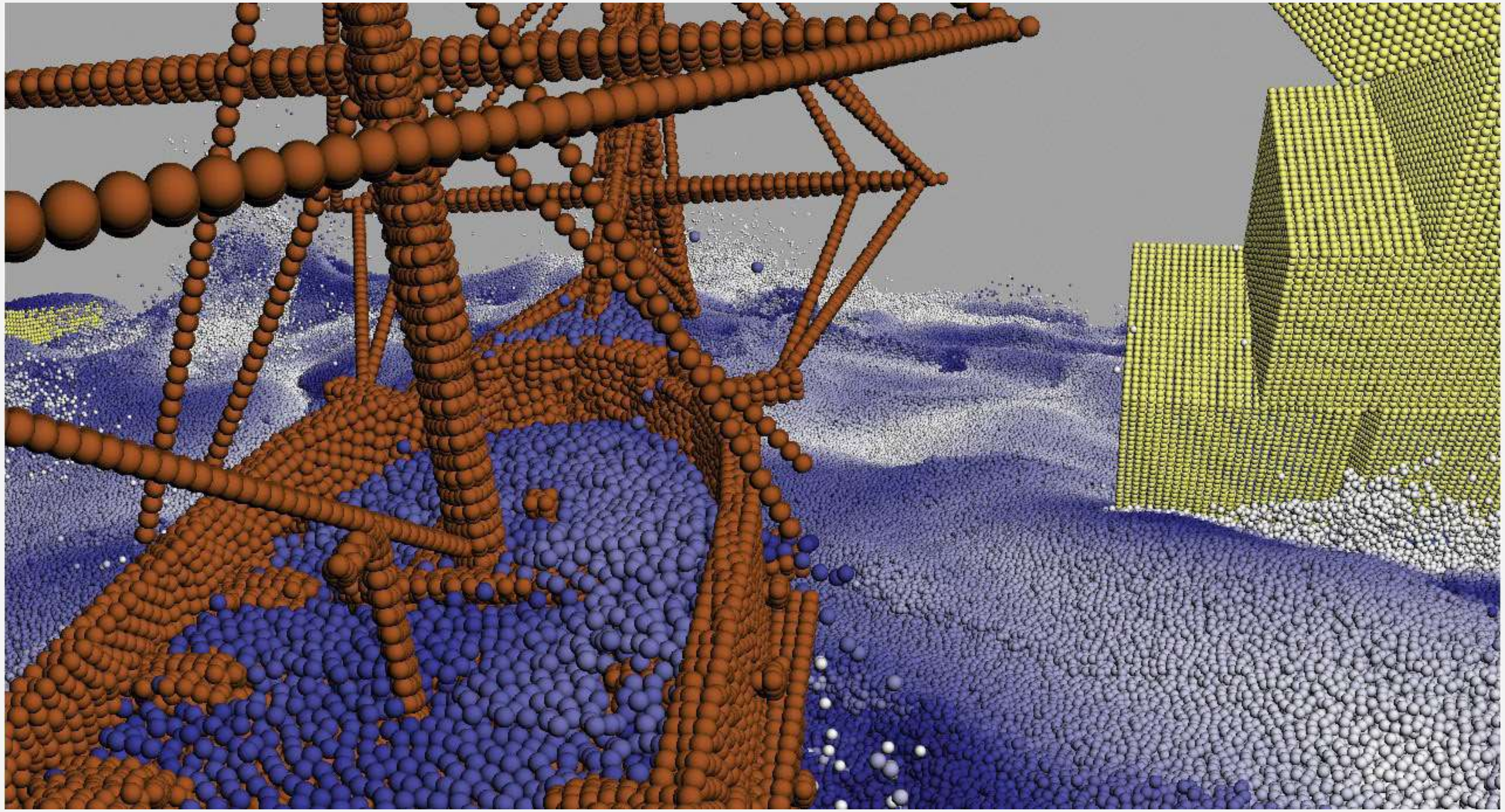
Fluids



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

Fluids



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Fluids

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

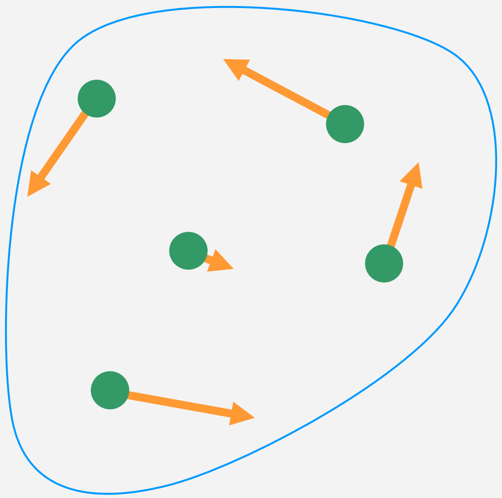
FIFTY2, PreonLab.

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

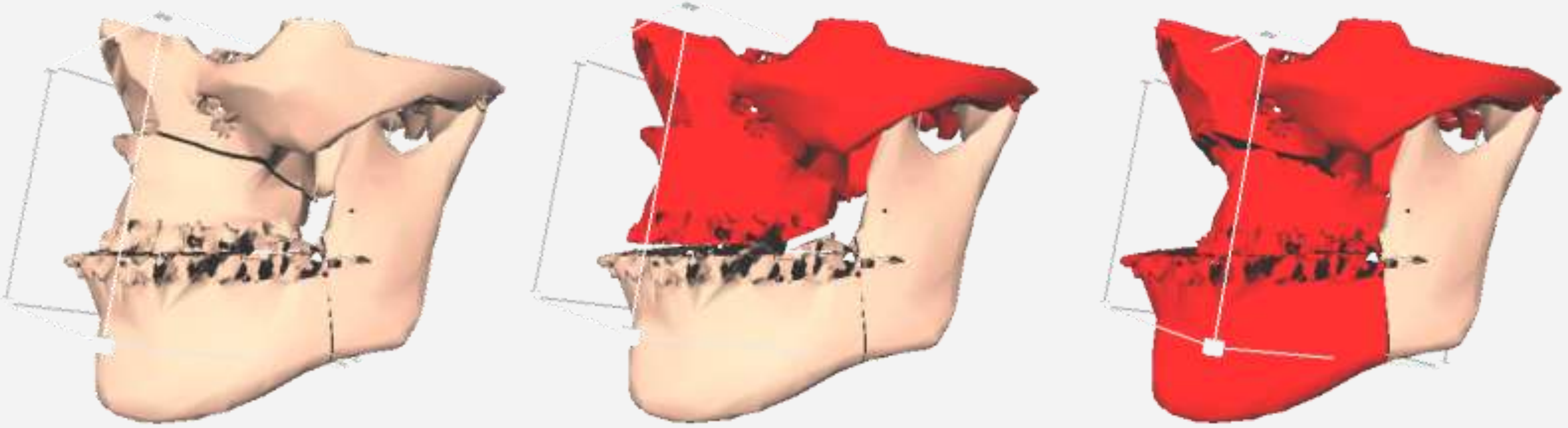


Topics

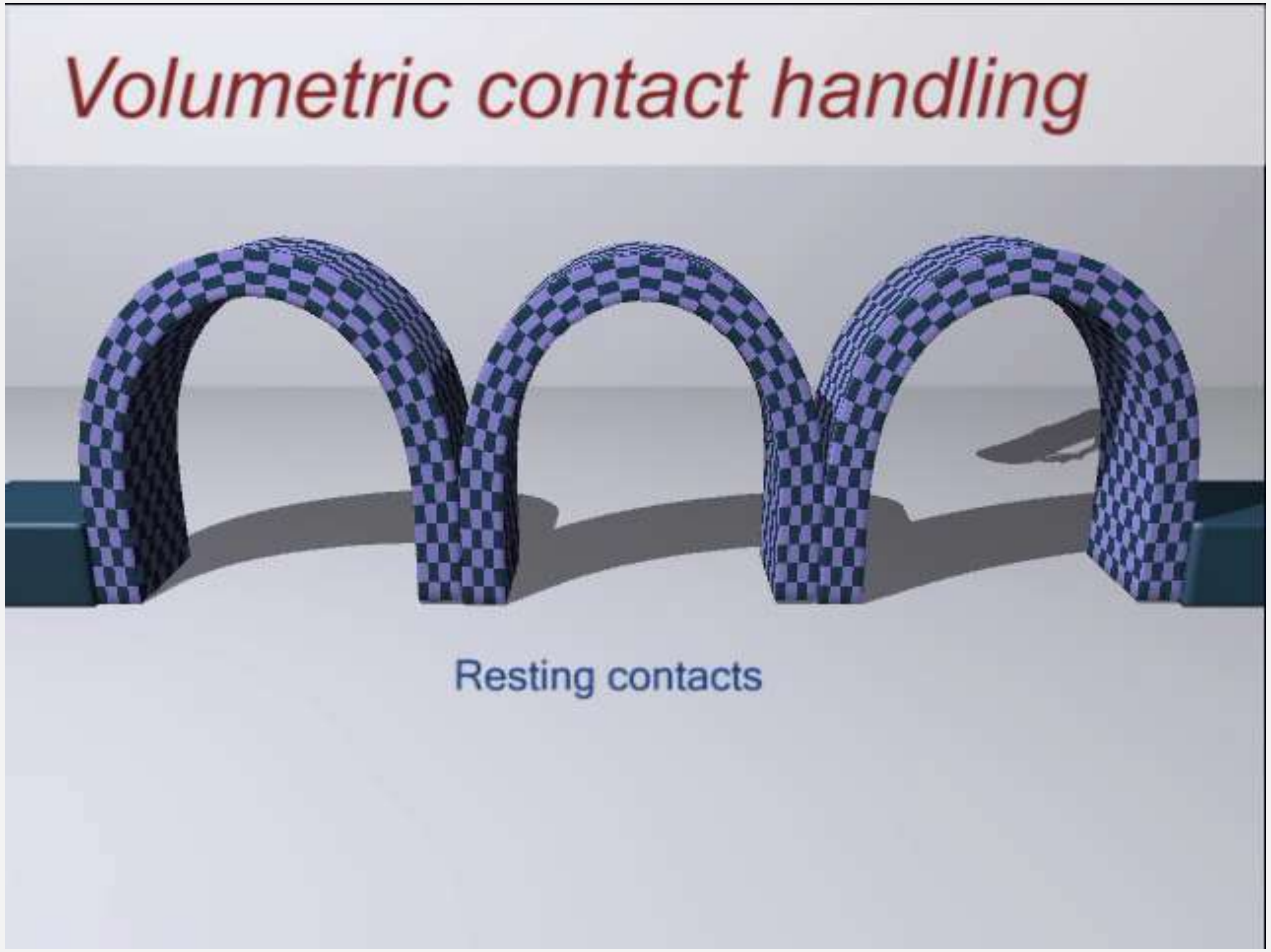
- Particle motion
- Deformable solids
- Fluids
- Rigid bodies
- Collision detection

Collision Detection

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



Collision Handling



Spillmann, Becker, Teschner, Journal of WSCG, 2007.

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

Outline

- Motivation
- Topics
- Organization

Exercises / Exam

- Exercises
  - By appointment
  - First exercise on Oct 24
  - Smaller exercises in the first part
  - Larger project towards the end
- Exam
  - Oral
  - Based on slide sets
  - Relevant material will be summarized

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