Seminar
Advanced Topics in Animation

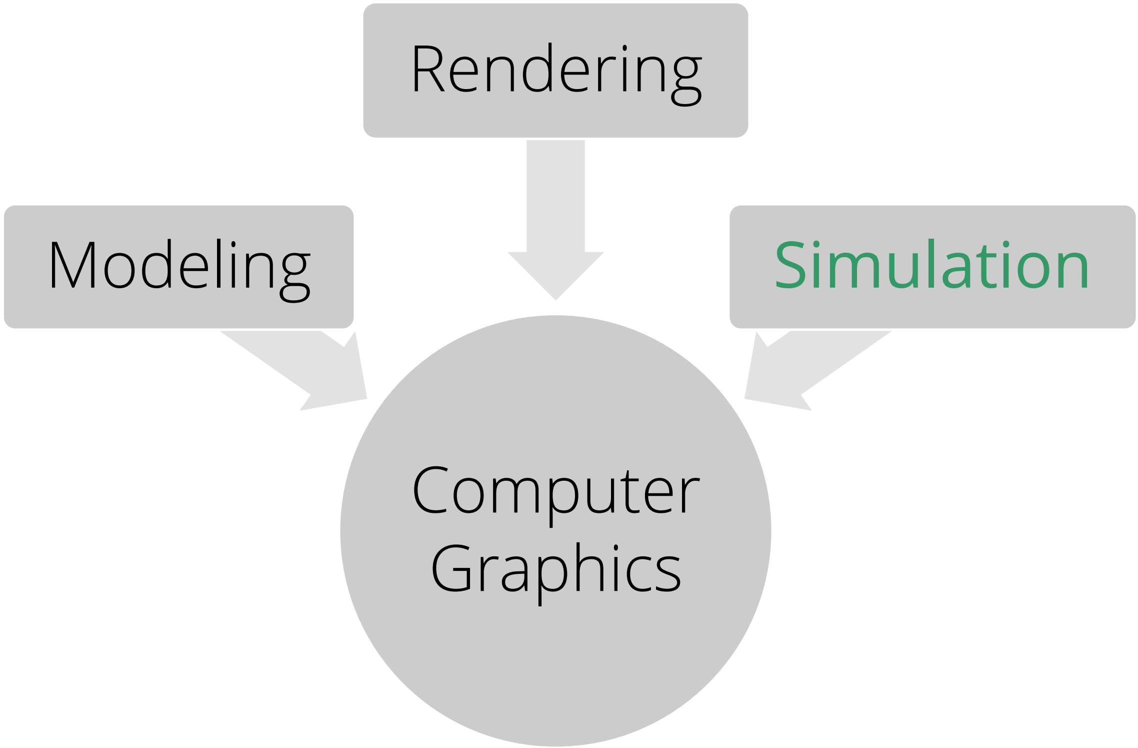
Matthias Teschner

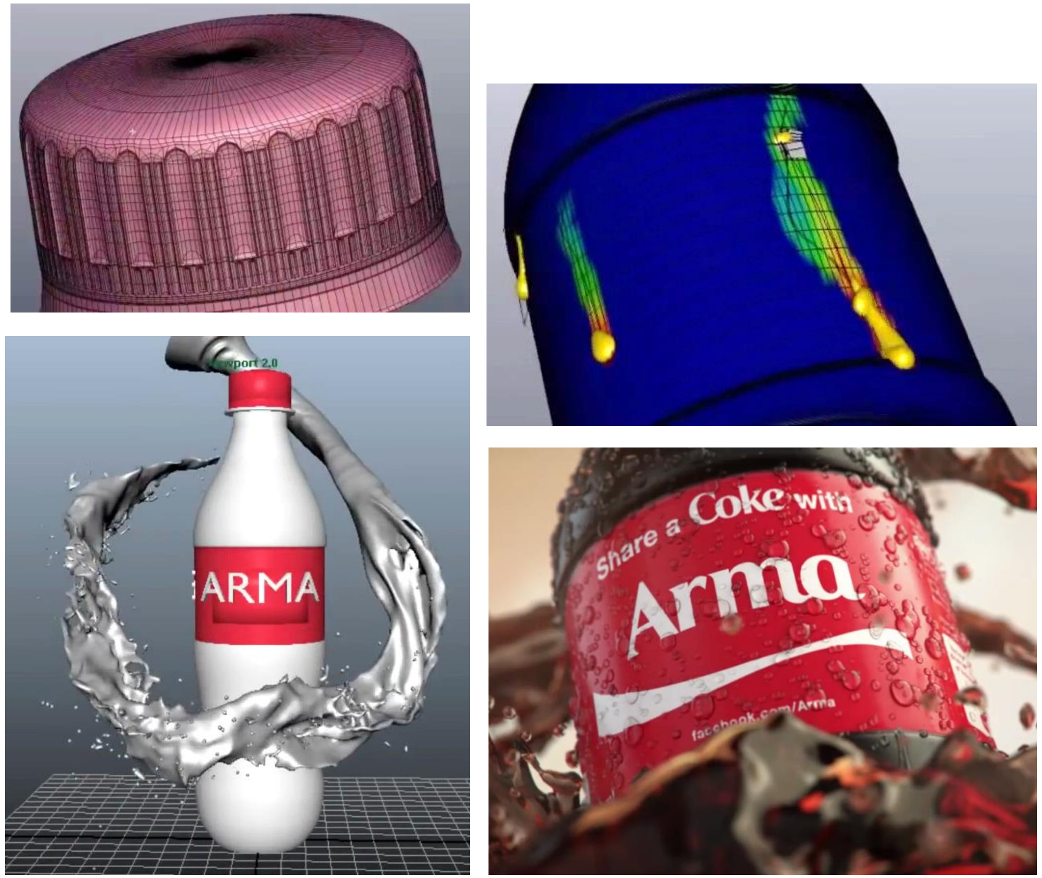
UNI FREIBURG

Outline

- Introduction
- Organization
- Presentation
- Topics
- Summary

Computer Graphics





CGI Making of Share a Coke VFX
Breakdown by ARMA

Graphics Courses

- Key course
  - Image processing and computer graphics (modeling, rendering, simulation)
- 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

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

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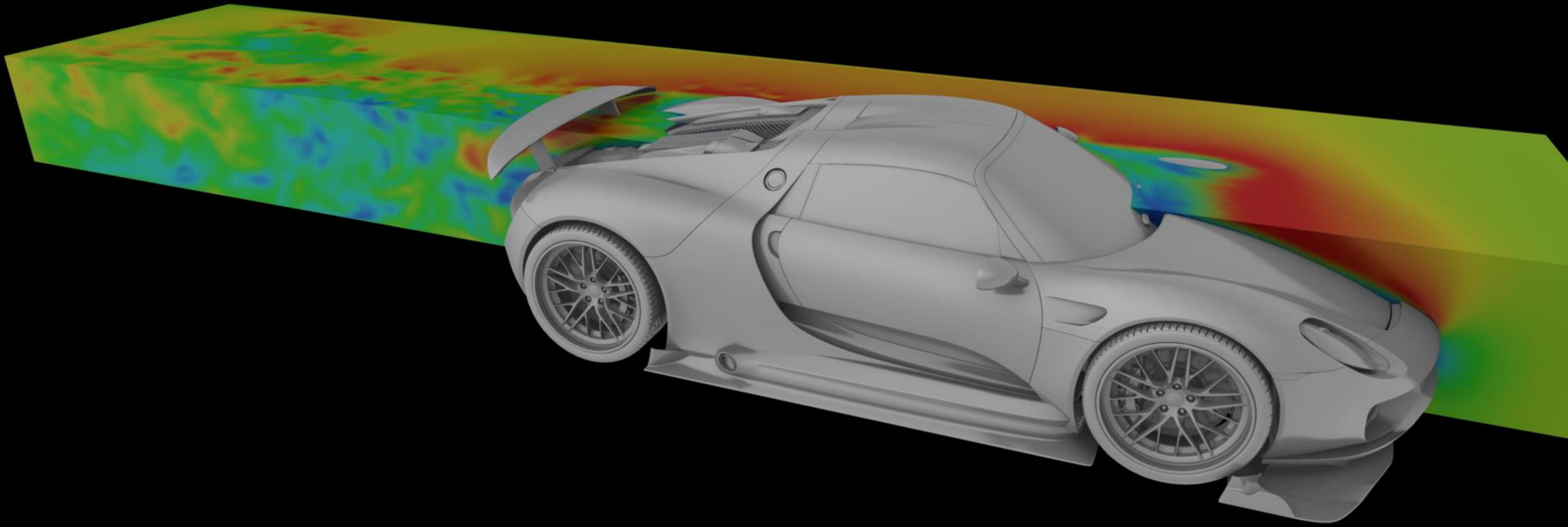
Gissler et al., ACM Transactions on Graphics, 2019



Band et al., Computer Graphics Forum, 2020.
Cooperation with FIFTY2 Technology GmbH.

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Requirements

- Oral presentation of an animation topic
  - English / German
  - Slides should be in English
- Written report
  - English / German

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Goal

- Familiarize yourself with a topic
- Prepare a comprehensible presentation
- Presentation should be based on a scientific publication
  - Do not just reproduce the manuscript
  - Adapt the organization and the focus of the document in order to get a comprehensible presentation

Presentations

- Take place at the same time and in the same room as the introduction or per video conference
  - Announced in the course catalog and on our web page https://cg.informatik.uni-freiburg.de/teaching.htm
    - Advanced Topics in Animation
      - Schedule
- Attendance is mandatory

Report and Submissions

- Written report (approx. 10 pages)
- Submission of presentation slides and written report in two separate PDF files
  - YourLastName_report.pdf
  - YourLastName_presentation.pdf
- Per email to Prof. Teschner
- Until the last day of lectures of the semester

Registration

- Check for available topics and dates
  - https://cg.informatik.uni-freiburg.de/teaching.htm
    - Advanced Topics in Animation
      - Schedule / Topics
- Send an email to Prof. Teschner with your registration request stating name, topic, date
- Do not forget to register for the seminar in the campus management system

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Presentation

- 25 min – 35 min per presentation
- 10 min – 15 min discussion
  - Technical questions
  - Form of the presentation

Preparation

- Know your topic
  - Examine relevant material thoroughly
  - Do not try to circumvent problems
- Create slides
  - Allow 1 to 2 minutes per slide
  - Slides should be uniform and not too dense
  - Incorporate illustrations, slide titles should be helpful
- Rehearse your presentation
  - Gather feedback, adapt your presentation accordingly

Presentation

- Introduction
  - Introduce yourself and the title of your presentation
- Overview
  - Give an idea, but not too detailed
- Motivation
  - Illustrate the principle and / or applications
  - Explain the goal of your presentation
  - The audience should be eager to listen your presentation

Presentation

- Main part
  - Should consist of distinguished sections
  - Separate different sections of the presentation explicitly
  - Each section should be introduced and summarized
- Summary
  - Tell the audience what you have told them
  - Ask for questions

Presentation

- Check the presentation environment prior to the presentation
- Avoid idiosyncrasies
- Stay in time

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Information

- https://cg.informatik.uni-freiburg.de/
  - Teaching
    - Advanced Topics in Animation
      - Schedule / Topics

Topics - Example

Neighbor Search in SPH Fluids

The neighbor search in SPH simulations is an expensive task. That's why, spatial data structures are investigated to accelerate the search. While the typically employed concept of a uniform grid is simple, its implementation offers some degrees of freedom with significant performance differences ...

Sources:

https://cg.informatik.uni-freiburg.de/intern/seminar/animation - SPH dataStructures - 2019.pdf

https://cg.informatik.uni-freiburg.de/intern/seminar/animation - SPH survey - 2019.pdf

Topics

– Concepts

Smoothed Particle Hydrodynamics, Material Point Method, Grid simulation, Position Based Dynamics, Rigid bodies

– Basics

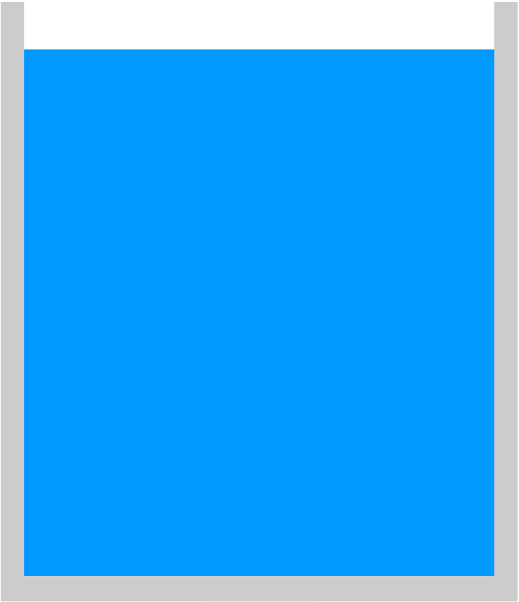
Continuum mechanics, numerical integration

– Data Structures

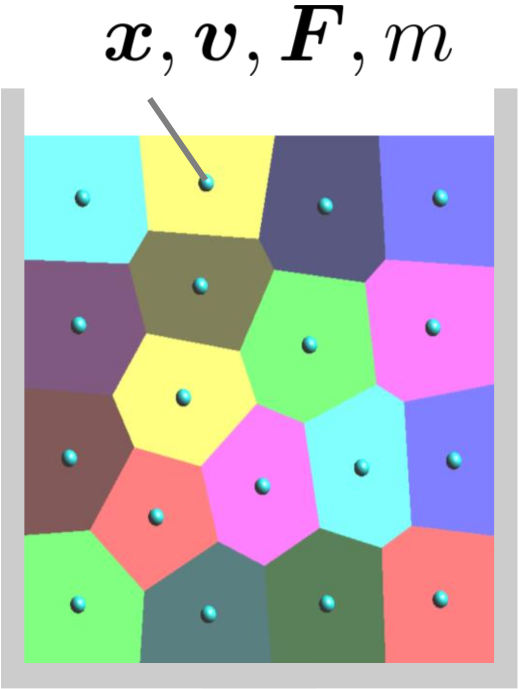
Space subdivision, Bounding volume hierarchies

Particle Simulation

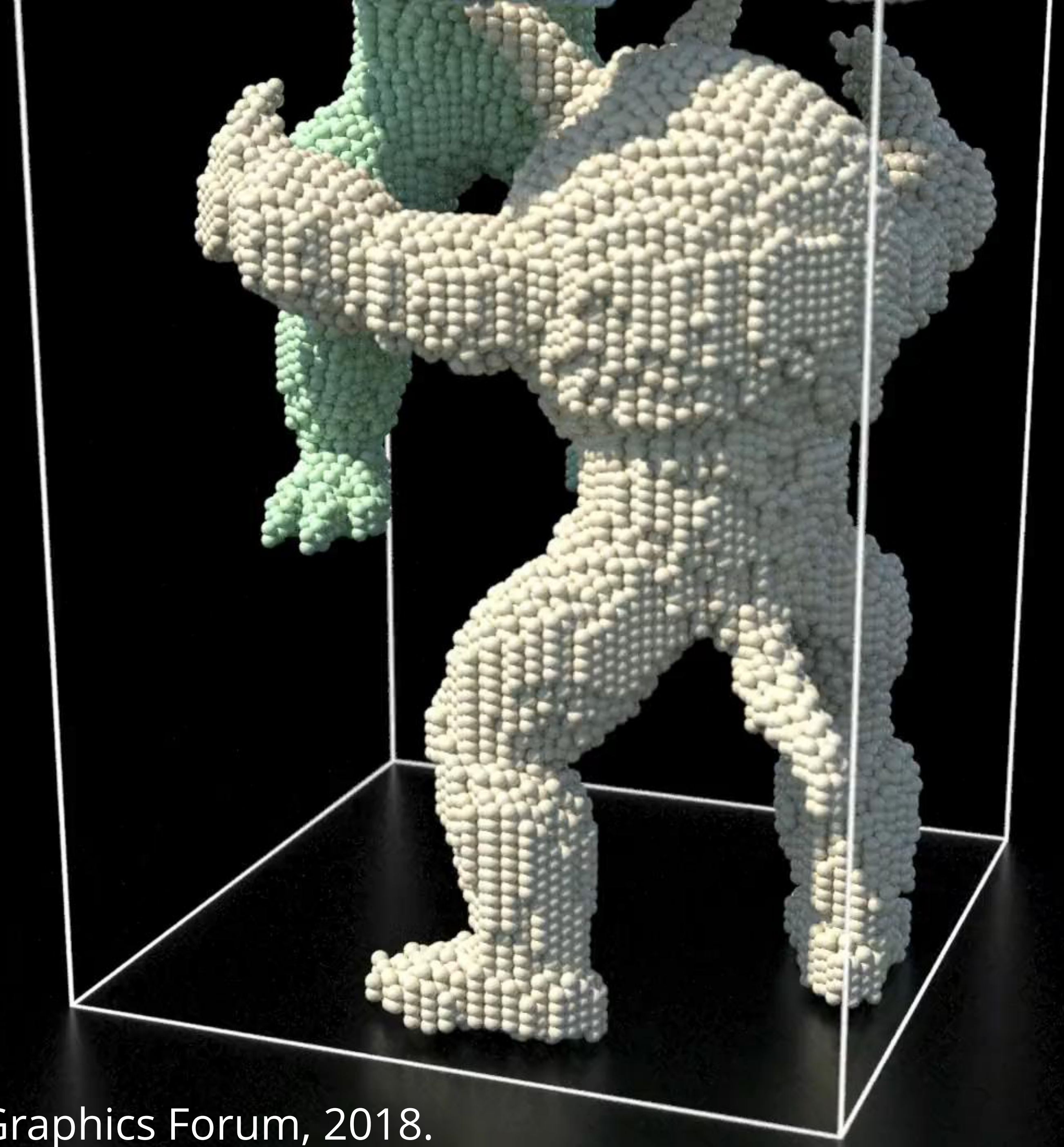
- Particles
  - Are small parts of solids and fluids with mass m
  - Move over time t with changing position $\boldsymbol{x}(t)$ and velocity $\boldsymbol{v}(t)$ due to forces $\boldsymbol{F}(t)$
- Motion governed by
  $\boldsymbol{F}(t) = m\frac{\mathrm{d}\boldsymbol{v}(t)}{\mathrm{d}t} = m\frac{\mathrm{d}^2\boldsymbol{x}(t)}{\mathrm{d}t^2}$
- Numerical integration to approximate $\boldsymbol{x}(t)$ and $\boldsymbol{v}(t)$



Fluid body



Fluid particles



Peer et al., Computer Graphics Forum, 2018.

Particle Simulation

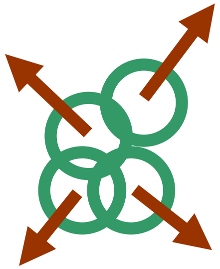
- Which material? What is a deformation?
  - Shear is a deformation of an elastic solid, but not of a fluid.
- How to get forces from deformations?
  - Displacement, strain, stress ⇨ continuum mechanics
- How to compute forces at particles?
  - Consider neighbors ⇨ Smoothed Particle Hydrodynamics

Particle Simulation

- How to find those neighbor particles?
  - Spatial data structures ⇨ space subdivision
- How to move the particles due to forces?
  - Acceleration is the time derivative of velocity is the time derivative of position ⇨ numerical integration

Continuum Mechanics - Example

– Handling of compression at a fluid particle



– Strain $\epsilon = \rho - \rho_0$

Deviation between actual density and rest density

– Stress $p = k\epsilon$

State equation

– Acceleration

$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = -\frac{1}{\rho}\nabla p$$

Navier-Stokes equation

SPH Fluid Solver

for all *particle i* **do**

  find neighbors j — Uniform grid (space subdivision)

for all *particle i* **do**

$$\rho_i = \sum_j m_j W_{ij}$$

Density (SPH)

$$p_i = k(\rho_i - \rho_0)$$

Pressure (continuum mechanics)

for all *particle i* **do**

$$\boldsymbol{a}_i^{\text{nonp}} = \nu \nabla^2 \boldsymbol{v}_i + \boldsymbol{g}$$

Non-pressure accelerations (SPH)

$$\boldsymbol{a}_i^{\text{p}} = -\frac{1}{\rho_i} \nabla p_i$$

Pressure acceleration (SPH)

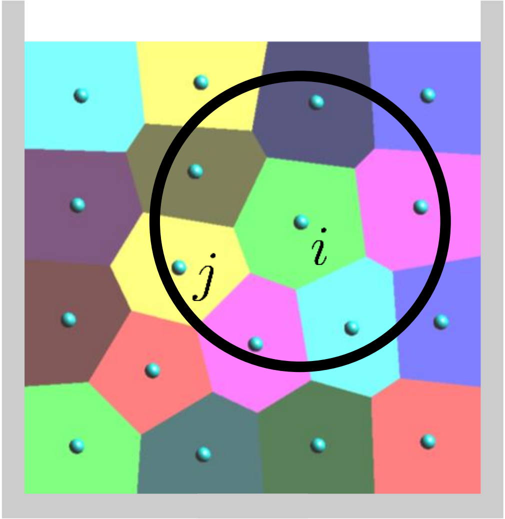
$$\boldsymbol{a}_i(t) = \boldsymbol{a}_i^{\text{nonp}} + \boldsymbol{a}_i^{\text{p}}$$

for all *particle i* **do**

$$\boldsymbol{v}_i(t+\Delta t) = \boldsymbol{v}_i(t) + \Delta t \boldsymbol{a}_i(t)$$

$$\boldsymbol{x}_i(t+\Delta t) = \boldsymbol{x}_i(t) + \Delta t \boldsymbol{v}_i(t+\Delta t)$$

Velocity and position update (Numerical integration, Euler-Cromer)



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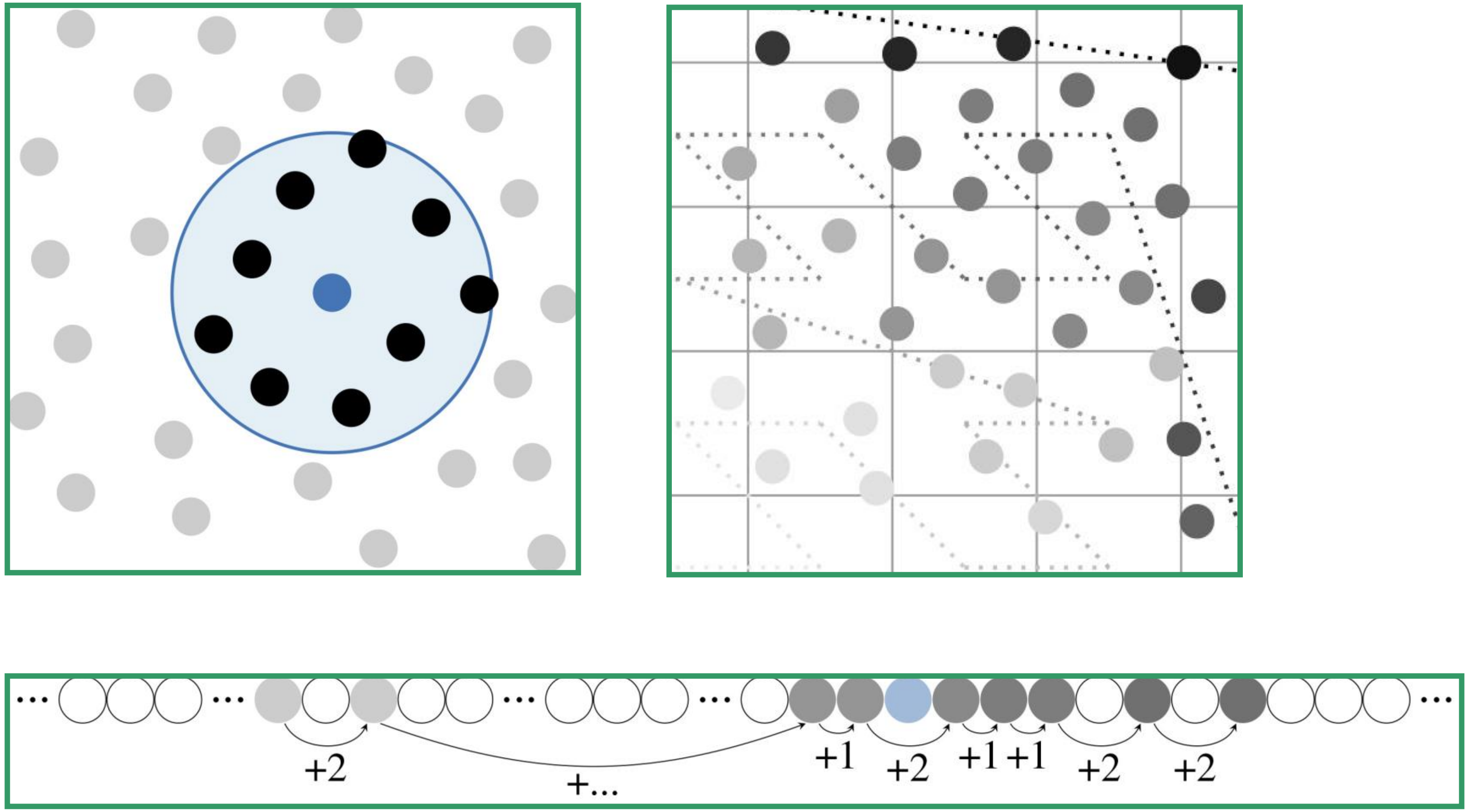
SPH Discretizations

- Density computation $\rho_i = \sum_j m_j W_{ij}$
- Pressure acceleration $-\frac{1}{\rho_i}\nabla p_i = -\sum_j m_j \left(\frac{p_i}{\rho_i^2} + \frac{p_j}{\rho_j^2}\right) \nabla W_{ij}$
- Viscosity acceleration $\nu \nabla^2 \boldsymbol{v}_i = 2\nu \sum_j \frac{m_j}{\rho_j} \frac{\boldsymbol{v}_{ij} \cdot \boldsymbol{x}_{ij}}{\boldsymbol{x}_{ij} \cdot \boldsymbol{x}_{ij} + 0.01h^2} \nabla W_{ij}$

- Can also be used to compute forces in elastic or elasto-plastic solids

Neighbor Search



Pressure Computation

- State equation (local)
- Solving a pressure Poisson equation (global)
  - Matrix-free implementation

$$p_i = k(\rho_i - \rho_0)$$

$$\nabla \cdot \mathbf{v}_i^* + \nabla \cdot \left(-\Delta t \frac{1}{\rho_i^t} \nabla p_i^t\right) = 0$$

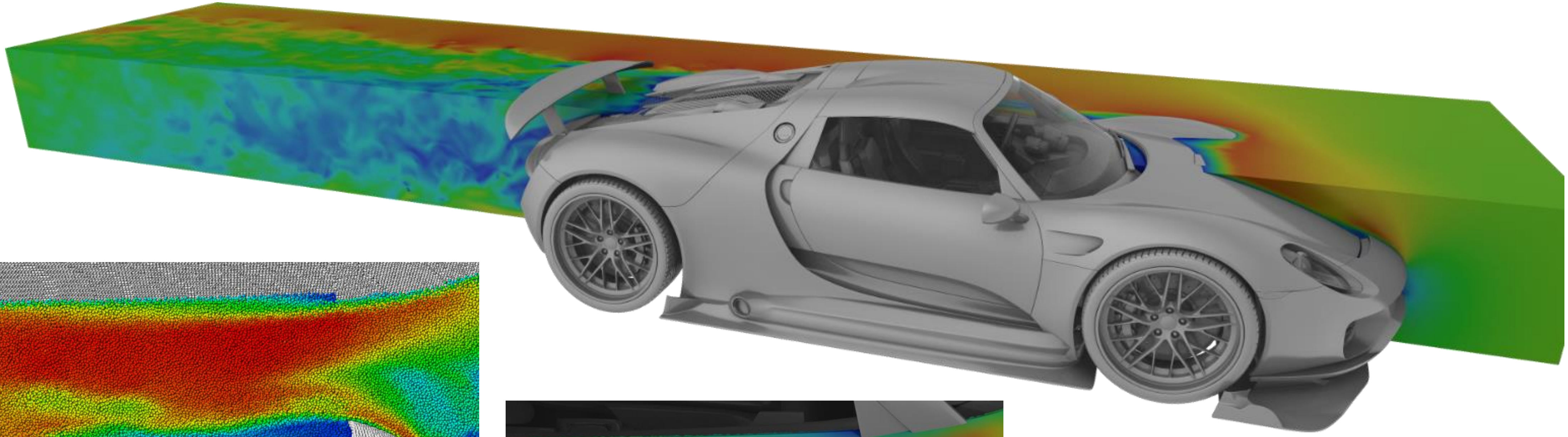
$$\Downarrow$$

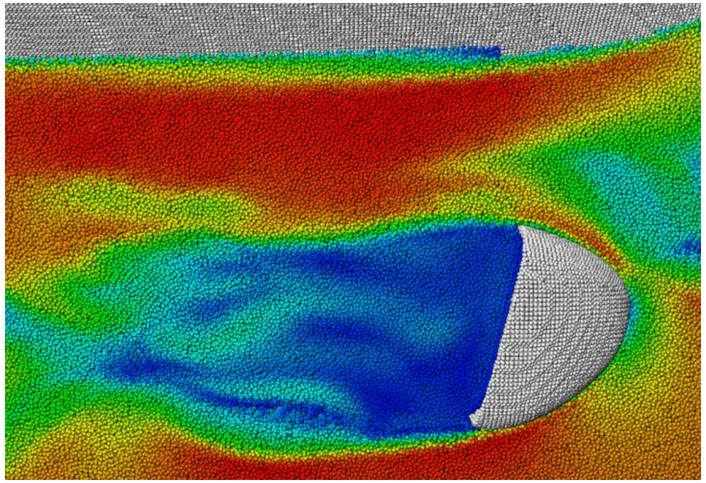
$$\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \begin{pmatrix} p_1^t \\ p_2^t \\ \vdots \\ p_n^t \end{pmatrix} = \begin{pmatrix} s_1 \\ s_2 \\ \vdots \\ s_n \end{pmatrix}$$

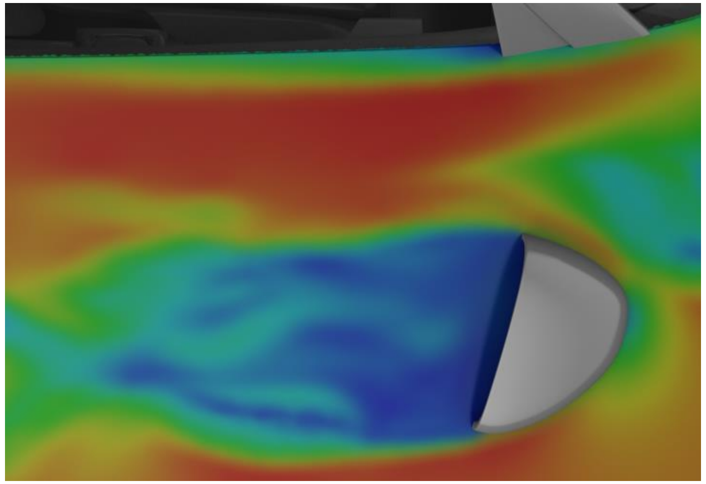
Boundary Handling

– Pressure forces preserve sample volumes

Boundary Handling







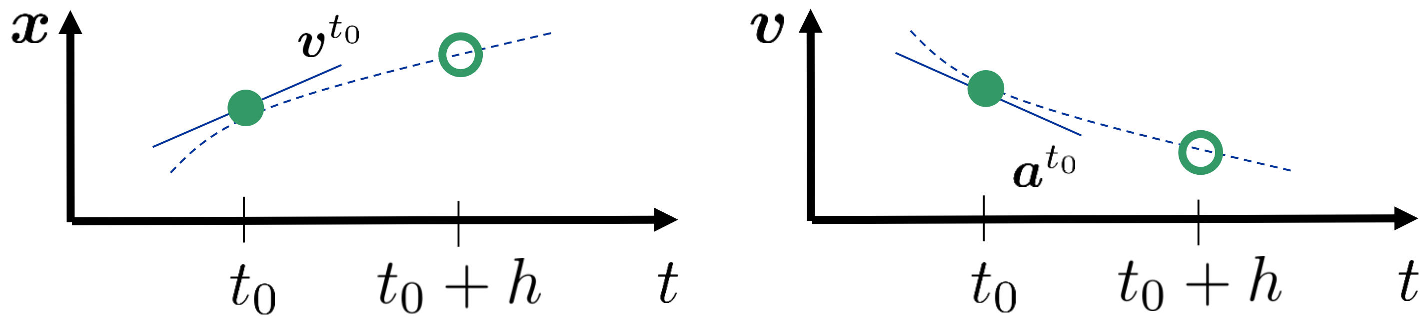
Band et al., Computer Graphics Forum, 2020. Cooperation with FIFTY2 Technology GmbH.

Numerical Integration

- Functions $\boldsymbol{x}^t$ and $\boldsymbol{v}^t$ represent the particle motion
- Initial values $\boldsymbol{x}^{t_0}$ and $\boldsymbol{v}^{t_0}$ are given
- First-order differential equations are given

$$\frac{\mathrm{d}\boldsymbol{x}^t}{\mathrm{d}t} = \boldsymbol{v}^t \quad \frac{\mathrm{d}\boldsymbol{v}^t}{\mathrm{d}t} = \boldsymbol{a}^t$$

- How to estimate $\boldsymbol{x}^{t_0+h}$ and $\boldsymbol{v}^{t_0+h}$?

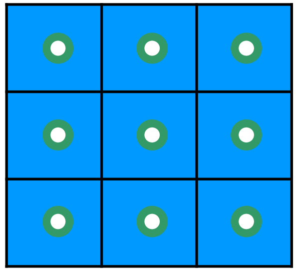


Fluids - SPH vs. MPM vs. FD

– All approaches compute velocity changes at sample positions, either static or advected

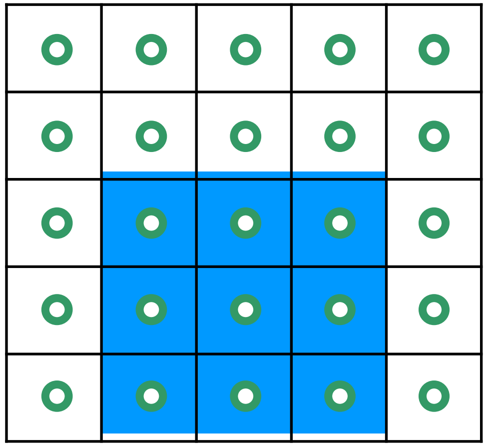
Acceleration
at advected
samples

SPH



MPM

uses static
and advected
samples



Acceleration
at static
samples

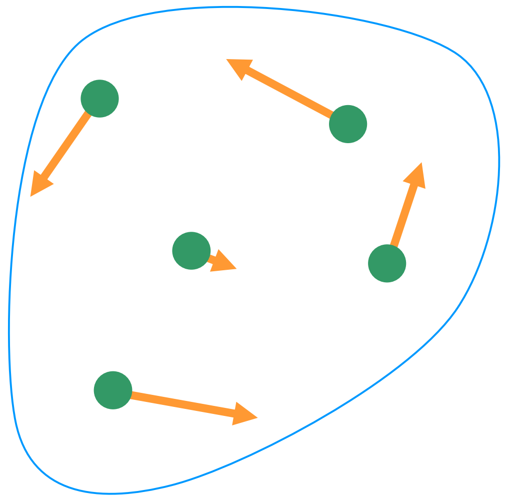
FD

$$\frac{\mathrm{d}\boldsymbol{v}}{\mathrm{d}t} = \boldsymbol{g} + \nu \nabla^2 \boldsymbol{v} - \frac{1}{\rho} \nabla p$$

$$\frac{\partial \boldsymbol{v}}{\partial t} = \boldsymbol{g} + \nu \nabla^2 \boldsymbol{v} - \frac{1}{\rho} \nabla p - (\boldsymbol{v} \cdot \nabla) \boldsymbol{v}$$

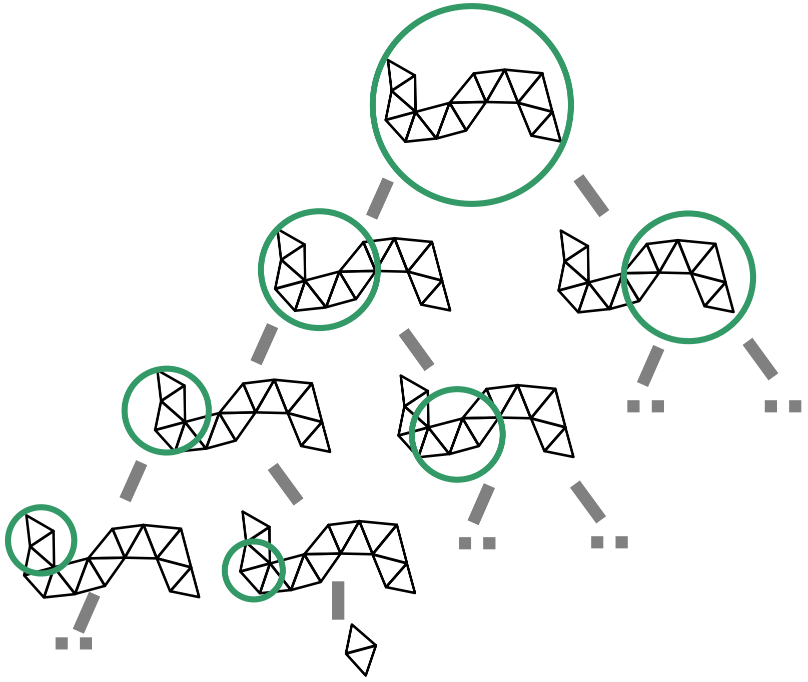
Rigid Bodies

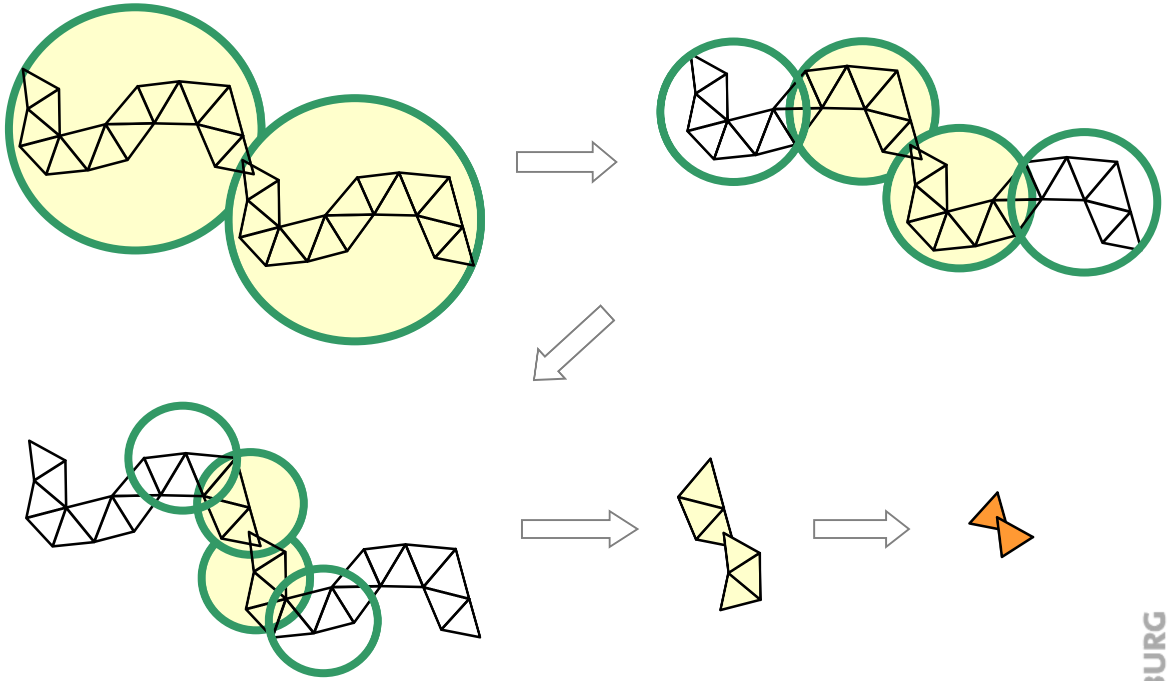
- Particles connected by springs with infinite stiffness
- Entire body described by one position and one orientation
- Forces at particles influence translation and rotation of the entire body
- Mass distribution, orientation, angular velocity, torque



Bounding Volume Hierarchies

- Alternative to space subdivision
- Useful for collision queries





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Summary

- Oral presentation of 25-35 min
- Written report of 10 pages
- Topics overview and presentation dates
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