Seminar
Advanced Topics in Animation

Matthias Teschner
Outline

- Introduction
- Organization
- Presentation
- Topics
- Summary
Computer Graphics

Modeling → Rendering → Simulation

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
<table>
<thead>
<tr>
<th>Semester</th>
<th>Simulation Track</th>
<th>Rendering Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Simulation Course</td>
<td>Key Course</td>
</tr>
<tr>
<td>Summer</td>
<td>Key Course</td>
<td>Lab Course - Simple Ray Tracer</td>
</tr>
<tr>
<td></td>
<td>Lab Course - Simple fluid solver</td>
<td>Rendering Seminar</td>
</tr>
<tr>
<td></td>
<td>Simulation Seminar</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>Master Project - PPE fluid solver</td>
<td>Rendering Course</td>
</tr>
<tr>
<td></td>
<td>Rendering Seminar</td>
<td>Master Project - Monte Carlo RT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulation Seminar</td>
</tr>
<tr>
<td>Summer</td>
<td>Master Thesis</td>
<td>Master Thesis</td>
</tr>
<tr>
<td></td>
<td>Research-oriented topic</td>
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</tr>
</tbody>
</table>
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Requirements

- Oral presentation of an animation topic
  - English / German
  - Slides should be in English
- Written report
  - English / German
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
- Do not occlude the projection
- Avoid idiosyncrasies
- Stay in time
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Information

- https://cg.informatik.uni-freiburg.de/
  - Teaching
    - Advanced Topics in Animation
    - Schedule / Topics
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:
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 $\mathbf{x}(t)$ and velocity $\mathbf{v}(t)$ due to forces $\mathbf{F}(t)$
- Motion governed by
  $$\mathbf{F}(t) = m \frac{d\mathbf{v}(t)}{dt} = m \frac{d^2\mathbf{x}(t)}{dt^2}$$
- Numerical integration to approximate $\mathbf{x}(t)$ and $\mathbf{v}(t)$
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 $\Rightarrow$ space subdivision

- How to move the particles due to forces?
  - Acceleration is the time derivative of velocity is the time derivative of position $\Rightarrow$ numerical integration
Continuum Mechanics - Example

- Handling of compression at a fluid particle

- Strain \( \epsilon = \rho - \rho_0 \)
- Stress \( p = k\epsilon \)
- Acceleration \( \frac{dv}{dt} = -\frac{1}{\rho} \nabla p \)

Deviation between actual density and rest density
State equation
Navier-Stokes equation
SPH Fluid Solver

for all particle $i$ do
  find neighbors $j$

for all particle $i$ do
  $\rho_i = \sum_j m_j W_{ij}$
  $p_i = k(\rho_i - \rho_0)$

for all particle $i$ do
  $a^{\text{nonp}}_i = \nu \nabla^2 \mathbf{v}_i + g$
  $a^p_i = -\frac{1}{\rho_i} \nabla p_i$
  $a_i(t) = a^{\text{nonp}}_i + a^p_i$

for all particle $i$ do
  $\mathbf{v}_i(t + \Delta t) = \mathbf{v}_i(t) + \Delta t a_i(t)$
  $\mathbf{x}_i(t + \Delta t) = \mathbf{x}_i(t) + \Delta t \mathbf{v}_i(t + \Delta t)$

Uniform grid (space subdivision)
Density (SPH)
Pressure (continuum mechanics)
Non-pressure accelerations (SPH)
Pressure acceleration (SPH)
Velocity and position update
(Numerical integration, Euler-Cromer)
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
  \[ \nu \nabla^2 \mathbf{v}_i = 2\nu \sum_j m_j \frac{\rho_j}{\rho_i} \frac{\mathbf{v}_{ij} \cdot \mathbf{x}_{ij}}{\mathbf{x}_{ij} \cdot \mathbf{x}_{ij} + 0.01h^2} \nabla W_{ij} \]

- Can also be used to compute forces in elastic or elasto-plastic solids
Neighbor Search
Pressure Computation

- State equation (local)
  \[ p_i = k(\rho_i - \rho_0) \]

- Solving a pressure Poisson equation (global)
  \[ \nabla \cdot \mathbf{v}_i^* + \nabla \cdot (-\Delta t \frac{1}{\rho_i} \nabla p_i^t) = 0 \]

  ↓

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

- Matrix-free implementation
Boundary Handling

– Pressure forces preserve sample volumes
Boundary Handling


University of Freiburg – Computer Science Department – 34
Numerical Integration

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

$$\frac{d\mathbf{x}^t}{dt} = \mathbf{v}^t \quad \frac{d\mathbf{v}^t}{dt} = \mathbf{a}^t$$

- How to estimate $\mathbf{x}^{t_0+h}$ and $\mathbf{v}^{t_0+h}$?
Fluids - SPH vs. MPM vs. FD

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

**SPH**

\[ \frac{dv}{dt} = g + \nu \nabla^2 v - \frac{1}{\rho} \nabla p \]

**MPM**

uses static and advected samples

**FD**

\[ \frac{dv}{dt} = g + \nu \nabla^2 v - \frac{1}{\rho} \nabla p - (v \cdot \nabla) v \]
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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