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

<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></td>
</tr>
<tr>
<td>Summer</td>
<td>Key Course</td>
<td>Key Course</td>
</tr>
<tr>
<td></td>
<td>Lab Course - Simple fluid solver</td>
<td>Lab Course - Simple Ray Tracer</td>
</tr>
<tr>
<td></td>
<td>Simulation Seminar</td>
<td>Rendering Seminar</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 Research-oriented topic</td>
<td>Master Thesis Research-oriented topic</td>
</tr>
</tbody>
</table>
Outline

- Motivation
- Topics
- Organization
Computer Graphics

Modeling → Rendering

Simulation

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

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)

Applications

– Computer-aided engineering (cooperation with FIFTY2)

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

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, ...
Applications

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

Interacting deformable objects
Outline

- Motivation
- 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 $\mathbf{v}(t)$
Versatile Materials

Deformable Solids

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

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

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
      \[ \Delta t \nabla^2 p_i = \frac{1}{\Delta t} (\rho_0 - \rho_i^*) \Rightarrow Ap = s \]
    - Required for volume preservation / zero velocity divergence
Fluids

Dam break

20M fluid particles

Fluids
Fluids


FIFTY2, PreonLab.
Fluids

CUP SCENE
KEYFRAMED ANIMATIONS - 1.2 M PARTICLES

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
– Monday, 16:15, Simulation in Computer Graphics
– Wednesday, 10:15, Rendering Seminar
– Wednesday, 12:15, Animation Seminar
– Thursday, 10:15, Proseminar Graphik
– Tuesday next week, 12:15, Simulation Tutorial
– Tuesday next week, 14:15, Rendering Tutorial
– No tutorials tomorrow
Acknowledgements

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