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

<table>
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<tr>
<th>Semester</th>
<th>Simulation Track</th>
<th>Rendering Track</th>
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<tr>
<td>Winter</td>
<td>Key Course</td>
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<td>Simulation Course</td>
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<td>Summer</td>
<td>Lab Course</td>
<td>Rendering Course</td>
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<td>- Simple fluid solver</td>
<td>Lab Course</td>
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<td>Simulation Seminar</td>
<td>- Simple raytracer</td>
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<td>Winter</td>
<td>Master Project</td>
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<td>- PPE fluid solver</td>
<td>- Monte Carlo raytracer</td>
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<td>Rendering Seminar</td>
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<td>Summer</td>
<td>Master Thesis</td>
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<td>- Research-oriented topic</td>
<td>- Research-oriented topic</td>
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Outline

– Motivation
– Topics
– Organization
Course Goals

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

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

Modeling → Computer Graphics → Rendering → Animation

CGI Making of Share a Coke VFX Breakdown by ARMA.

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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)

Applications

– Computer-aided engineering (cooperation with FIFTY2)

FIFTY2 Technology GmbH, PreonLab, 2016.
Applications

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

Applications

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

Applications

– Art (cooperation with Studio Claudia Comte)


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.
Applications

– Robotics

Support of robot navigation in environments with deformable objects

Acceleration of robot navigation with simulation environments
Applications

- Entertainment technologies
  - 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
  - Model generation
  - Dynamics
  - Collision handling
  - Constraints

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
  $$\mathbf{F}(t) = m \frac{d\mathbf{v}(t)}{dt} = m \frac{d^2\mathbf{x}(t)}{dt^2}$$
- Numerical integration to approximate $\mathbf{x}(t)$ and $\mathbf{v}(t)$
Particle Systems

– Particle sets can be used to mimic dynamic effects
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

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

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

Fluids

- Velocity change at particle is computed as sum over adjacent particles.
- 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
      \[ \Delta t \nabla^2 p_i = \frac{1}{\Delta t} (\rho_0 - \rho_i^*) \Rightarrow A p = s \]
    - 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
Collision Handling

Volumetric contact handling

Resting contacts

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
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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
Acknowledgements

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