Simulation in Computer Graphics

Introduction

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Course Information

– 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 in Graphics

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<td>Summer</td>
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<td>- Simple fluid solver</td>
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<td>Winter</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

Simulation

Computer Graphics

Rendering

CGI Making of Share a Coke VFX Breakdown by ARMA.

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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 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
  – Modeling
  – Dynamics
  – Constraints, e.g. collisions

Interacting deformable objects
Terminology

- Physically based animation
- Simulation
- Computer aided engineering
  - E.g., computational fluid dynamics
- High-performance computing
  - Large scenarios
- Real-time physics
  - Interactive scenarios
Outline

- Motivation
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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

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

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

$$-rac{1}{\rho_i} \nabla p_i(t) = - \sum_j m_j \left( \frac{p_i}{\rho_i^2} + \frac{p_j}{\rho_j^2} \right) \nabla W_{ij}$$
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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– Organization
Exercises / Exam

- Exercises
  - By appointment
  - First exercise on Oct 30
  - Voluntary

- Exam
  - Oral
  - Based on slide sets
  - Relevant material will be summarized
Acknowledgements

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