Physically-Based Simulation

Due: Feb 27
Check-In: *Sunday,* Feb 16

Overview: Last assignment, we simulated fuzzy phenomena using dense systems of loosely interacting particles that followed some procedural set of rules for how they evolved over time. The goal of this assignment is to simulate various systems that follow well-defined physical laws. In the process, you should gain familiarity with different techniques commonly used to animate complex physical phenomena, such as differential equations, numerical integration, and spatial data-structures.

Requirements: Write (at least) two physically-based simulation demos. One, a simulation of cloth interacting with an object. The second, can be a significantly more advanced cloth simulation, a fluid simulation, sound simulation, or deformable or rigid-body dynamics. You may work with a partner, have one partner turn in the full assignment and the other submit a note saying who they worked with.

Check-in: There is mandatory mid-way check-in. For this, you must turn in a webpage with a video (& code) of a simulated thread (or several threads) of cloth. The thread(s) must be anchored at the top and allowed to dangle free on the bottom. Note, for the check-in, we only need the vertical threads – adding horizontal (cross) threads is optional, they will make the simulation less stable, so only try it second.

Strongly Suggested Features
(5) Realtime rendering (must document framerate)
(5) 3D rendering, with user-controlled camera (must rotate and translate)
(5) Real-time user interaction with system

Cloth-Object Interaction (1-way coupling object-to-cloth) [up to 40 points]
(10) 2D Mass-spring cloth simulation
(10) 3D Mass-spring cloth simulation *[cumulative over 2D]*
(10) Drag-terms (must include demo showing effect of drag)
(10) 1-way cloth-object interaction (extra points for non-spherical objects)

*Cloth Performance Benchmarks (cumulative)**
(5) 15x15 Cloth with fast, smooth motion at 20 FPS
(5) 20x20 Cloth with fast, smooth motion at 30 FPS
(5) 30x30 Cloth with fast, smooth motion and obstacle interaction at 30 FPS
*If your cloth moves slowly you will get no credit for performance benchmarks

General Features
Integrator
(5) Eulerian (1st order)
(5) Higher-order Explicit (e.g., Midpoint, RK4, Lax–Wendroff)
(10) Implicit Integrator
(5) Compare two or more integration methods in terms of speed & stability

Rendering
(10) Textured simulated objects (e.g., textured cloth)

Acceleration
(5) Thread-parallel implementation (must document performance gain)
(10) SIMD / GPU implementation (must document performance gain)
(20) Spatial-data structure – must show a performance improvement

Additional Features
(10) Two-way coupling object-simulation coupling (e.g., cloth moves a ball)
(10) Integrate 2D rigid body sphere-sphere interactions for several spheres
(20) Integrate 3D rigid body sphere-sphere interactions for several spheres
(20) Combine (3D) rotational rigid body dynamics with another simulation

Advanced Cloth
(5) Billowing/blowing wind effect simulated with aerodynamic drag
(5) Skip nodes spring/threads to stiffen cloth (must show comparison)
(10) Tear-able cloth.
(15) Burnable cloth (should have particle effects for full credit)
(20) Self-collision in cloth
(40) Finite Element Method (FEM)-based cloth simulation

Water/Fluid Simulation
(10) 1D Water surface, with shallow water equation
(10) 2D Water surface, with shallow water equation *[cumulative over 1D]*
(30) 2D Eulerian fluid simulation (e.g. Stam GDC '03)
(50) 3D Eulerian fluid simulation

*2D Water/Fluid Performance Benchmarks (cumulative)**
(5) 50x50 Shallow Water Sim. at 20 FPS
(5) 100x100 Shallow Water Sim. at 30 FPS
(5) 100x100 Eulerian Fluid at 20 FPS
(5) 200x200 Eulerian Fluid at 30 FPS
*If your water moves slowly you will get no credit for performance benchmarks

Hair Simulation
(20) 2D hair simulation (can't miss collisions between strands)
(20) 3D hair simulation (can't miss collisions between strands) *[cumulative over 2D]*
(10) Angle-based dynamics (must document effect)

Deformable Objects
(20) 2D deformable objects (must show rotational effects)
(10) 3D deformable objects (must show rotational effects) *[cumulative over 2D]*

Rigid-Body Dynamics w/ Rotation
(30) Make 2D rotational rigid body dynamics simulation (10+ non-circle objects)
(60) Make 3D rotational rigid body dynamics simulation (5+ non-sphere objects)

More things to simulate
(30) Physical simulated (polyphonic) music instrument with user interaction

Art Contest: 5 points for honorable mentions, the winner gets 10 points.

Scoring
Partial credit will be given. Scores computed as follows (points above 100 possible):
-*Undergraduate*: Grade is √(totalPoints * 100) [e.g., 100 points will be full credit]
-*Grad students*: Grade is √(totalPoints * 84) [e.g., 120 points will be full credit]

Use of other code and tools
Anything you are getting credit for must be code you wrote specifically for this course, clearly specify any external libraries you are using.

What to turn in
You must make a submission webpage with:

- Images & video of your systems
- A brief description of the features of your implementation
- Code you wrote
- List of the tools/library you used
- Brief write-up explaining difficulties you encountered
- Submission for the art contest (optional)

Remember, if you don't tell us about it, we can't give you credit for it.

Hints
-Use small timesteps
-There is a lot flexibility here. If you aren't sure what to do, go for a cloth simulation that interacts with a user-controlled ball. Use a spatial data-structure to accelerate cloth-ball collision detection.
-Make your simulations stable using just a few elements before you try highly detailed cloth or water.
-There are both easy paths and hard paths through the assignment. Don't let it become too big of a time sink, but do try to have fun with it.
-Use a small timestep!
-Show off your system doing something interesting (e.g., let your cloth detach and fall onto something). It's easier to give good grades to nice simulations. =)

Simulation Grading Guide

Cloth-Object Interaction (one way coupling object-to-cloth)

A-level *(35-40 points)*:
The cloth falls smoothly to its resting position and moves at a natural speed. The motion of the cloth is smooth, and it naturally drapes over an object in the scene. The effect of the aerodynamic drag term are clear in the cloth's motion.

B-level *(30-35 points)*:
The cloth looks a bit like it's moving in "slow-mode", but the behavior is otherwise smooth and stable. The cloth is affected by the object, but the motion at times looks a little unnatural (maybe the motion is slightly bumpy, or there are overly big gaps between the cloth and the object).

C-level *(20-25 points)*:
The cloth falls down due to gravity, but it does not consistently fall in a stable path to its resting state. The cloth's interaction with the obstacles in the scene is unstable or unnatural.

Additional Features *(various points)*:
This simulation is a natural point to add mouse-based user interaction by letting them control the ball/object that the cloth interacts with. Additionally, your cloth simulation can likely be speed up through a parallelized implementation (which is both points on its own and might increase your performance benchmarks). You may also want to try texturing the cloth to look more visually interesting. Once you have Eulerian integration working, you may want to try midpoint (or RK4) to see if you can get a larger timestep.

Advanced Cloth *[various points]*

A-level *(85-100% of the relevant features' points)*:
The cloth moves with smooth, natural, real-time motion. The simulation scenario is clearly different than the basic cloth, and showcases interesting motion and new types of simulations and interactions.

B-level *(70-85% of the relevant features' points)*:
The cloth looks like it is moving in "slow-mode" and/or this new simulation doesn't show case substantially different motion types than the first cloth simulation. The added elements effect the motion of the cloth, but there may be some unnaturalness to the motion, or the effect of the new simulation elements are somewhat subtle.

C-level: *(55-70% of the relevant features' points)*:
The motion of the cloth is different from the first cloth simulation, but not in a way which showcases the new features very clearly (e.g., in one simulation the cloth falls horizontally, the other vertically). Or the features added look somewhat unnatural in the way the interact with the cloth.