# Mass-spring Systems

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## Introduction

This project focuses on simulating a series of physically-based simulation models of elastic/flexible objects using the mass-spring approach. Below I'll be explaining how the spring and mass classes are implemented, and after that, I'll talk about each simulation specifically.

## Mass Struct

I've added a Boolean field to the mass struct called air resistance and whenever it's true, I add air resistance force to it. I implemented the integration function which uses a semi-implicit Euler method, which means that I use the current velocity to calculate the next step velocity, and then use the next step velocity and current position to calculate the next position of the mass.

## Spring Struct

I've added force_a and force_b functions. force_a calculates the applied force to mass_a, using the formula for spring force using the rest length, current length, and k_s constant, and after that the applied damping force is applied and the total force is returned. force_b function just returns -1 * force_a() based on Newton's Law.

## First Simulation – Mass on a Spring

For the first simulation, I set up a spring and two masses, connecting the two masses to the spring, one of them being fixed to their position. I set up my constants (k_s = 2, k_d = 0.1, dt = 0.001) and gave the second mass an initial velocity to see the spring in action.

In the step function, I apply the gravity and spring forces to each of the masses, and at the end, I call the integrate function to the masses. The spring and masses behave as expected.

## Second Simulation – Chain Pendulum

This simulation is pretty much like the previous one, except I used 20 masses with a distance of 1 and a spring between each pair of masses. I also had to change my spring constants significantly, because with previous constants, the springs extend too much. I had to increase k_s and k_d significantly (k_s = 1000, k_d = 5), and my dt remained the same.

The step function is also similar, except I added air resistance force to the masses so that the pendulum would stop swinging after some time. The air resistance is dependent on the velocity of the mass squared times a constant called c_d (c_d = 0.05). The chain pendulum acts as expected.

## Third Simulation – Cube of Jelly

For this simulation, I used a cube (width = 7, height = 6, depth = 5) and I connected each mass to its adjacent masses in all directions, and also to keep the overall form of the jelly, I connected the masses along the three dimensions of the cube (k_s = 250, k_d = 0.05). I also added an initial torque to the jelly to better see the effect of the collision.

I also added a collision system by defining a height for the ground, and whenever a mass falls below that height (y < height), a temporary spring force is added to the mass from the ground with the rest length of 0 and an extremely high k_s (k_s = 100000, k_d = 0.4) so that the cube doesn't go through the ground so much.

Adding the gravity, collision, air resistance, and spring forces, I integrate all the forces for all of the masses and the cube behaves as expected.

Also, I used a TriangleSoup to make faces on the outside of the cube to make it like a cube. I used the face struct set all three masses for each face and rendered them with triangles.

## Fourth Simulation – Hanging Cloth

For the hanging cloth, I used a 31x41 mass grid and connected each adjacent mass horizontally, vertically, and diagonally (k_s = 5000, k_d = 0.5). I fixed two masses, so the cloth is hanging. I also changed c_d to 0.0025 and dt to 0.002 to have the best effect on the cloth before it stopped swinging. The other steps are very similar to the other simulations.

## Conclusion

In conclusion, this project successfully demonstrated the versatility and robustness of the mass-spring model in simulating the dynamic behavior of elastic objects. Through the implementation of air resistance, semi-implicit Euler integration, and force calculations, we were able to observe realistic movements in a variety of scenarios. From the simple oscillation of a mass on a spring to the complex interactions within a cube of jelly, each simulation provided valuable insights into the physics of elasticity and resistance. The chain pendulum and hanging cloth simulations further showcased the model's ability to handle multiple interconnected masses and respond to external forces like gravity and air resistance. The TriangleSoup implementation for rendering the cube's faces and the cloth added a visual dimension that enhanced the understanding of the simulations. Overall, the project not only achieved its goal of simulating physically-based models but also paved the way for future explorations into more intricate and larger-scale simulations.