Physics Collision Simulator

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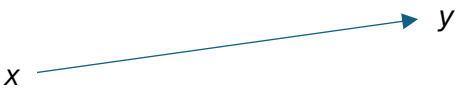
Background

2D Vectors

A 2-dimensional vector is a physical quantity that has a **magnitude** and a **direction**. Common vector quantities in physics include displacement, velocity, acceleration, and force. These quantities are essential in describing motion and interactions in a more complete way than scalars alone.

Mathematically, we can define a vector as follows:

$$\vec{V} = \langle x, y \rangle$$



Here:

- x is the horizontal component (along the x-axis)
- y is the vertical component (along the y-axis)

The vector originates from the tail at the origin and points toward the head at the coordinate (x, y).

Scalars

A scalar is a physical quantity that only has a magnitude and do not have a direction. Examples of scalar quantities are heat, speed, distance, and mass. For instance, if a car is traveling at 60 km/h, this value only tells us how fast it is moving, not where it is going.

Mathematically, a scalar can be represented as follows:

$$s \in \mathbb{R}$$

Distance and Displacement

Distance and **displacement** both describe the change of a body's position but are fundamentally different in physics.

Distance is a scalar quantity that refers to the total length of the path traveled by an object, regardless of the direction. It is always a positive value or zero, and it simply accumulates the ground covered during motion. For example, if a

person walks 3 meters east and then 4 meters west, the total distance traveled is 7 meters.

$$d = |d_i| + |d_2| + \ldots + |d_n|$$

Displacement, by contrast, is a vector quantity. It refers to the overall change in position from the starting point to the final position, taking direction into account. In the same example, where the person walks 3 meters east and 4 meters west, the displacement is 1 meter to the west, because the final position is 1 meter to the left (or negative side) of the starting point. Displacement can be positive, negative, or even zero if the object returns to its original position.

$$\Delta\vec{x} = \vec{x}_f - \vec{x}_i$$

Speed and Velocity

Closely related to distance and displacement are the concepts of speed and velocity. **Speed** is a scalar quantity that measures how fast an object is moving, calculated as the total distance divided by the time taken. It tells us how quickly an object covers ground but not the direction in which it travels. For example, if a car travels 100 kilometers in 2 hours, its speed is 50 km/h.

$$s = \frac{d}{t}$$

Velocity, on the other hand, is a vector quantity that considers both the rate of motion and its direction. It is defined as the displacement divided by the time taken. Therefore, if a car's displacement is 60 kilometers east in 2 hours, its velocity would be 30 km/h to the east. If the car returned to its starting point in the same amount of time, its velocity would be zero, even though it traveled some distance, because the displacement would be zero.

$$\therefore \vec{v} = \frac{\Delta\vec{x}}{\Delta t}$$

Gravity

Gravity is a fundamental force of nature that attracts objects with mass toward each other. On Earth, gravity gives weight to objects and causes them to fall when dropped. The gravitational acceleration on Earth is approximately 9.8 meters per second squared (m/s^2), meaning that, in the absence of air resistance, any object falling freely near Earth's surface will increase its downward velocity by 9.8 m/s every second. This acceleration is denoted by the symbol g, and it's responsible for the curved trajectories of projectiles and the motion of objects in free fall.

$$g = 9.8\ m.s^{-2}$$

In the collision simulator, the gravitational acceleration has been scaled down to 0.98 to create a slower, more visually appealing animation. Even though it's not exactly Earth's gravity, the same physics principles apply. Objects in the simulator constantly accelerate downward due to gravity, and when they hit the floor, their vertical velocity reverses (bounces) depending on how much energy is lost in the collision.

Energy and Friction

In physics, energy is the capacity to do work. It comes in many forms, such as kinetic energy (the energy of motion), potential energy (stored energy based on position), thermal energy, chemical energy, and more. One of the most important principles in physics is the conservation of energy, which states that energy cannot be created or destroyed, only transformed from one form to another.

When an object moves, it possesses kinetic energy, given by the formula

$$K = \frac{1}{2}mv^2$$

where m is the mass of the object and v is its velocity. If an object is held at a height in a gravitational field, it has gravitational potential energy, calculated by

$$U = mgh$$

where g is the gravitational acceleration and h is the height.

When forces act on objects, like friction, gravity, or collisions, energy is transferred or transformed. For instance, kinetic energy can be converted into heat and sound during a collision. Even when energy seems "lost," it's not destroyed, it's just changed into forms we might not be tracking, this is explained in the **1st Law of Thermodynamics**. Understanding how energy flows and transforms is central to analysing motion and interactions in physics.

Friction is a force that opposes motion between two surfaces in contact. It acts in the opposite direction to the movement and is caused by microscopic irregularities between the surfaces, even those that lokk smooth. There are two main types of friction: **static friction**, which prevents objects from starting to move, and **kinetic (or dynamic) friction**, which resists the motion of objects that are already moving. The force of friction depends on two factors: the roughness of the surfaces and the normal force (the force pressing the surfaces together). It's often calculated using the formula

$$f = \mu N$$

where f is the frictional force, μ is the coefficient of friction (a value that depends on the materials' surface), and N is the normal force. Friction is essential in everyday life, it allows us to walk without slipping, cars to grip the road, and objects to eventually come to rest. However, friction also causes energy dissipation, usually in the form of heat, which is why moving parts in machines can get hot. In physics problems, friction is a crucial non-conservative force that can affect motion, reduce energy efficiency, and influence the outcome of collisions.

Understanding these fundamental concepts is crucial to understanding how the collision simulator is done.

Physics Simulator

Too lazy to tie all this together ngl