

Classroom Demonstration Programs

Demonstration Programs Used in Class

Simulate an imaginary world.

Bouncing ball, balloon, etc.

Based on simple physical models.

$\vec{F} = m \vec{a}$, and not much more.

Programs make use of:

CPU graphics programming (Vulkan).

GPU graphics programming (OpenGL shader language).

CPU and GPU physics programming (CUDA on GPU).

Bouncing Ball Simulation

Simulates a ball bouncing over a platform.

Purpose is to show overall program structure ...
... and simple physical simulation.

These Notes

First, we'll describe the simulation physics.

Then the overall program structure will be described.

Simulation of a Bouncing Ball

Representation of Ball

Position: p , a three-element vector: $\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$.

Velocity: v , a three-element vector: $\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix}$.

Representation in demo-1-simple.cc:

```
class Ball {  
public:  
    pCoor position;  
    pVect velocity;  
};
```

Model for Ball Free Motion

We should already know that under constant acceleration a :

$$v(t) = v(0) + at$$

$$\begin{aligned} p(t_1) &= p(0) + \int_0^{t_1} v(t) dt \\ &= p(0) + \int_0^{t_1} (v(0) + at) dt \\ &= p(0) + v(0)t_1 + \frac{1}{2}at_1^2 \end{aligned}$$

In demo-1-simple.cc:

```
ball.position +=  
    ball.velocity * delta_t + 0.5 * gravity_accel * delta_t * delta_t;
```

What about the platform?

Model for Platform Collision

Let's keep things simple:

The platform is at $y = 0$.

If there is a collision with the platform ...

... the y component of the velocity will be multiplied by -0.9 .

The ball will bounce off more slowly than it hit.

The factor -0.9 is not special, just a typical non-ideal bounce.

$$v(t) = \begin{cases} v(0) + at & \text{if } t \leq t_c \\ -0.9[v(0) + at_c] + a(t - t_c) & \text{if } t > t_c \end{cases}$$

where t_c is the time of collision.

The equation above only considers the first bounce.

Closed-Form Doability

Closed-Form Equations for $v(t)$ and $p(t)$?

Should we re-write the equations for $v(t)$ and $p(t)$ for any t ?

The discontinuity (platform collision) makes things tedious.

But it is still doable for an undergraduate.

But, what if there were two balls?—or three?

Then, a closed-form expression would be impossible.

Discrete Interval Simulation

Idea: Consider short time periods called *time steps*.

The overall simulation will occur over many time steps.

Within a time step separately consider:

Free motion (without collisions).

Collisions.

```
for ( double time = 0;  time < end_of_time;  time += delta_t )  
{  
    // Each iteration computes one time step.  
    simulate_free_motion();  
    detect_and_resolve_collisions();  
}
```

Simulation of Free Motion

Determine forces on object.

Gravity.

Contact.

From forces and mass determine acceleration.

From acceleration update velocity.

Update position.