

# Game Technology

Lecture 8 – 5.12.2014  
Physics 1



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# Preliminary timetable

Lecture No.	Date	Topic
1	17.10.2014	Basic Input & Output
2	24.10.2014	Timing & Basic Game Mechanics
3	31.10.2014	Software Rendering 1
4	07.11.2014	Software Rendering 2
5	14.11.2014	Basic Hardware Rendering
6	21.11.2014	Animations
7	28.11.2014	Physically-based Rendering
<b>8</b>	<b>05.12.2014</b>	<b>Physics 1</b>
9	12.12.2014	Physics 2
10	19.12.2014	Procedural Content Generation
11	16.01.2015	Compression & Streaming
12	23.01.2015	Multiplayer
13	30.01.2015	Audio
14	06.02.2015	Scripting
15	13.02.2015	AI

## Today

- As easy as possible
- Build a simple demo with
  - Particle system
  - Colliding spheres
- Understand the basic principles

## Next week

- Build upon what we have learned
- Look at more complicated cases
- Apply the physics to our game

# Where we are headed

## „Marbellous“

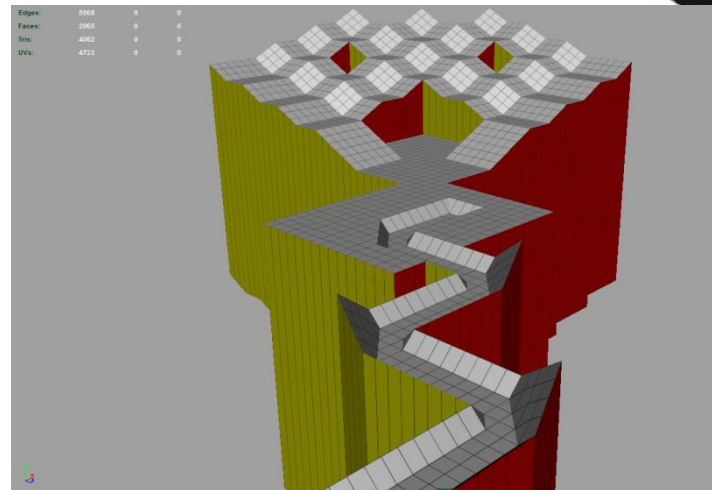
- Clone of „Marble Madness“ (1984)
- Roll a marble through a maze

## Ball Physics

- Apply force based on key inputs
- Bounce off off the level geometry
- (Fall from too high)

## Level

- Provided as a mesh
- „2D in 3D“



# Physics gone wrong...



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## Skyrim

<https://www.youtube.com/watch?v=O2UDHkTITMk>

## Skate 3

<https://www.youtube.com/watch?v=UaUR6u8nHoM>

## Assassin's Creed

<https://www.youtube.com/watch?v=WyovOrA64B8>

## Crysis

<https://www.youtube.com/watch?v=YG5qDeWHNmk>



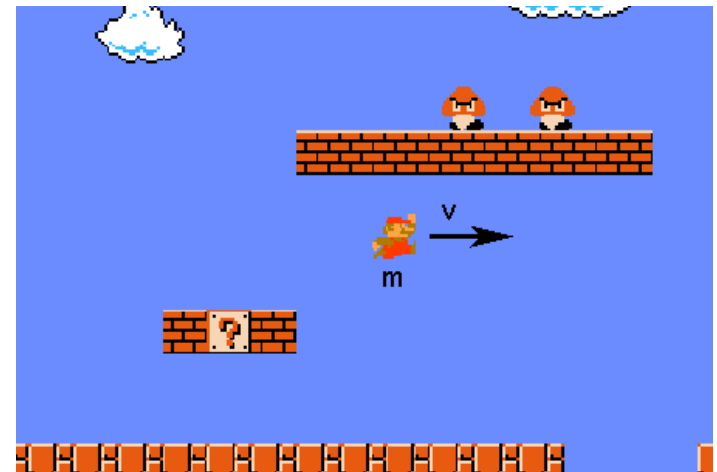
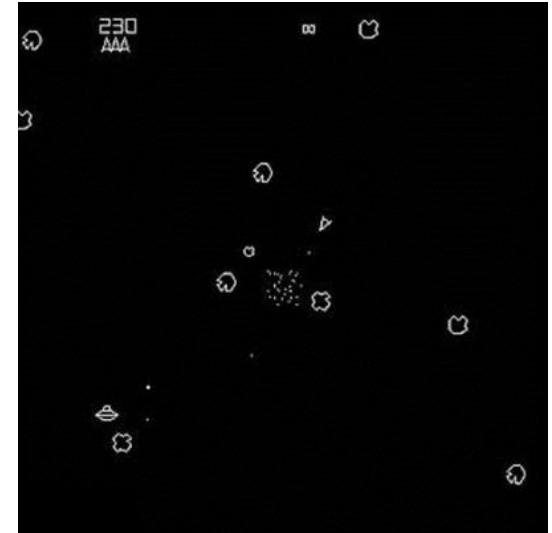
# Physics History

## Special-Purpose Physics

- Like the games, built for one purpose/game
- E.g. Asteroids, Marble Madness, ...

## Built for enjoyment and good gameplay feeling

- Physical accuracy not important
- E.g. Mario's momentum and friction



## 3D Physics

- Now more important to get realistic feel
- Started out with solutions developed in-house
- E.g. Trespasser (1998), own engine

## Ragdoll Physics

- Physical Simulation for articulated bodies
- Previously only for unconscious characters
- Now mixed with forward kinematics

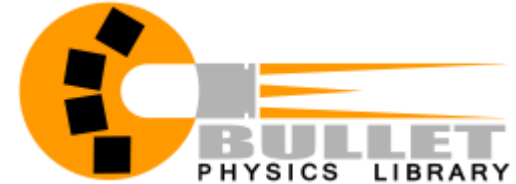




# General-Purpose Physics

## Libraries – Re-usable for different games

- Bullet
- Box2D
- ...



## Hardware Acceleration

- Nvidia Physx
  - Uses CUDA General-Purpose GPU Calculations
  - E.g. for particle systems





# Newtonian Physics

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**Isaac Newton**  
**1643 - 1727**

# Newton's three laws

- I. Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.
- II. The relationship between an object's mass  $m$ , its acceleration  $a$ , and the applied force  $F$  is  $F = ma$ . Acceleration and force are vectors (as indicated by their symbols being displayed in slant bold font); in this law the direction of the force vector is the same as the direction of the acceleration vector.
- III. For every action there is an equal and opposite reaction.

# Law #1

Every object in a state of uniform motion tends to **remain** in that state of motion unless an **external force** is applied to it.

## Examples of forces

- Gravity
- Drag
- Explosions
- ...

→ If we have an object that is just floating in space, simulation is very easy

→ Just continue with the same velocity in the same direction

## Law #2

The relationship between an object's **mass  $m$** , its **acceleration  $a$** , and the applied force  **$F$**  is  **$F = ma$** . Acceleration and force are vectors (as indicated by their symbols being displayed in slant bold font); in this law the direction of the force vector is the same as the direction of the acceleration vector.

### Mass $m$

- Measures the mass, not the weight
- The property that resists changes in linear or angular velocity

### Acceleration $a$

- Measure of the change of velocity

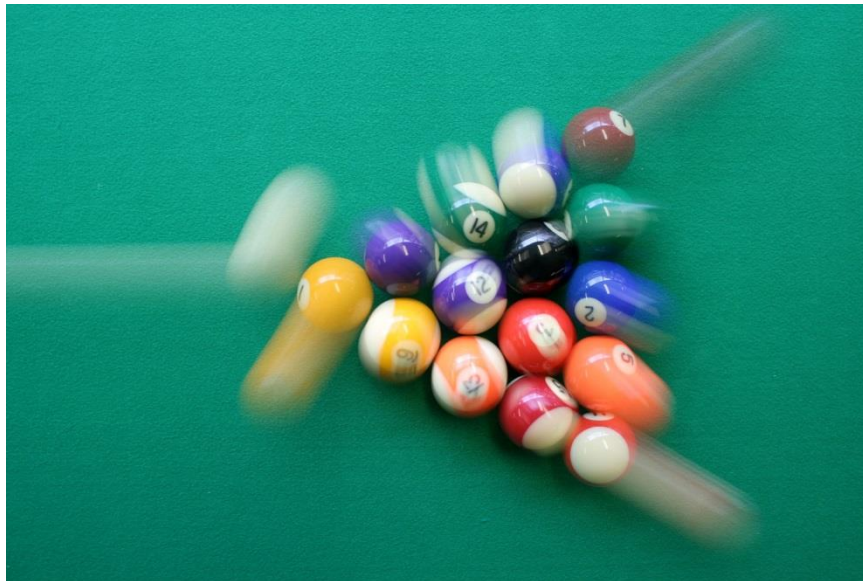
### Force $F$

# Law #3

For every action there is an **equal and opposite reaction**.

**We need to take care of this when we are simulating collisions**

- Collision Detection
  - Collision Response
- This is where the fun begins ;-)

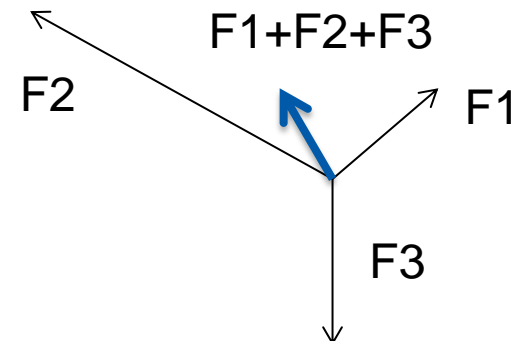
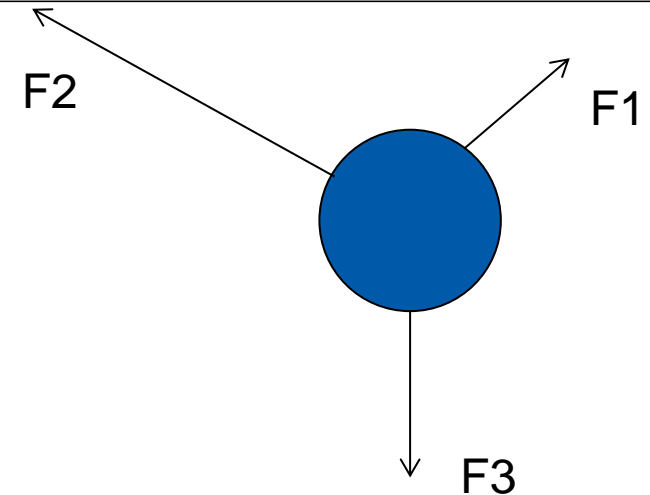


# D'Alemberts Prinicple

**Forces being applied to an object  
add up (Vector sums)**

**Will save us computational time  
and make code more readable**

- Calculating the effect of each force individually
  - Vs
- Accumulating forces and calculating the effect of the sum of the forces



# Particle Systems

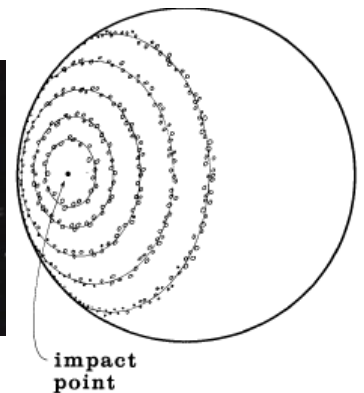
## Particle

- Infinitesimally small object
  - No need to calculate rotations, forces off-center
  - No volume



## Origins

- William T. Reeves: „Particle Systems A Technique for Modeling a Class of Fuzzy Objects” (1983)
- Worked on “Star Trek 2 – The Wrath of Khan”



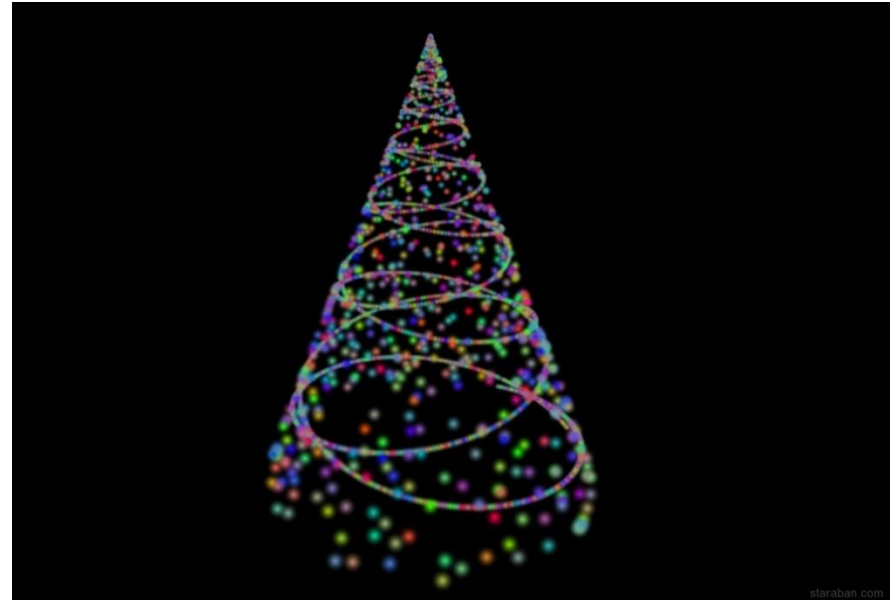


## Use in Games today

- Gaseous effects
  - Fire
  - Smoke
  - Gasses
- Explosions
- Atmospheric effects

## Basis for advanced techniques

- Cloth simulation
- Hair simulation
- Fluid simulation

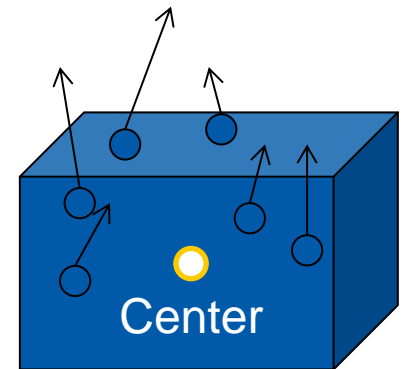


## Emitter

- Geometric shape in which the particles are spawned
- Spheres
- Boxes
- Complex polyhedra (meshes)
- Planes
- ...

## Emission Control

- Position (on faces, vertices, edges, inside the volume, ...)
- Random positioning of the emitted particles
- Number of particles
- Initial velocity
- Other particle properties

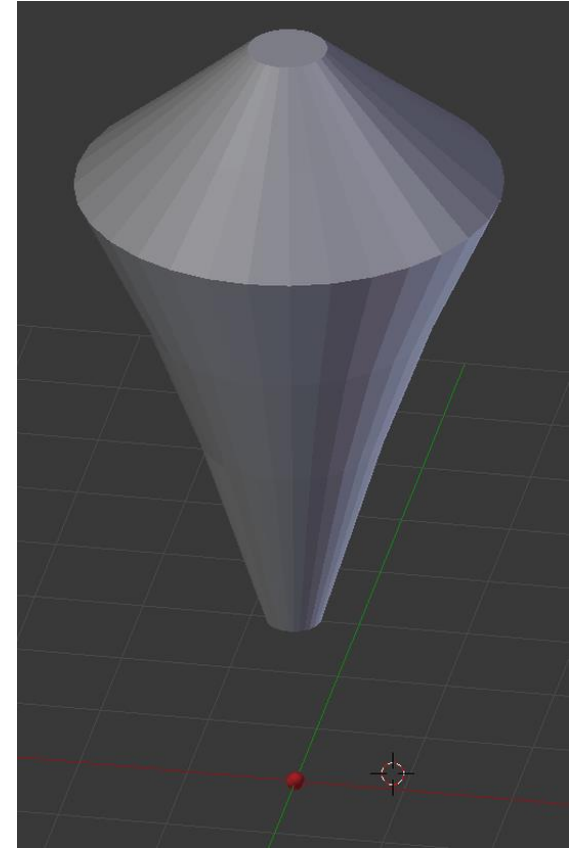


# Example – Particle systems shaping objects

**Goal: Render an amorphous/gaseous “alien”**

## Two particle systems

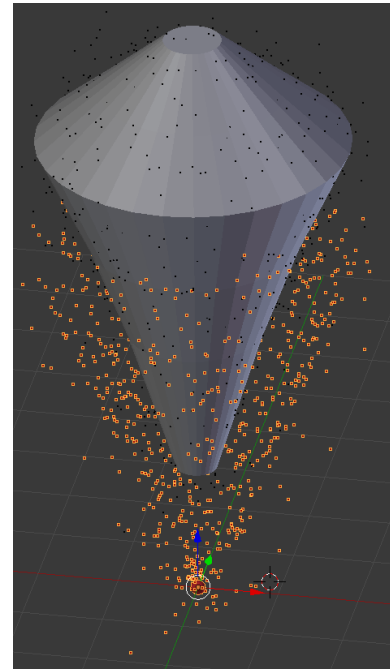
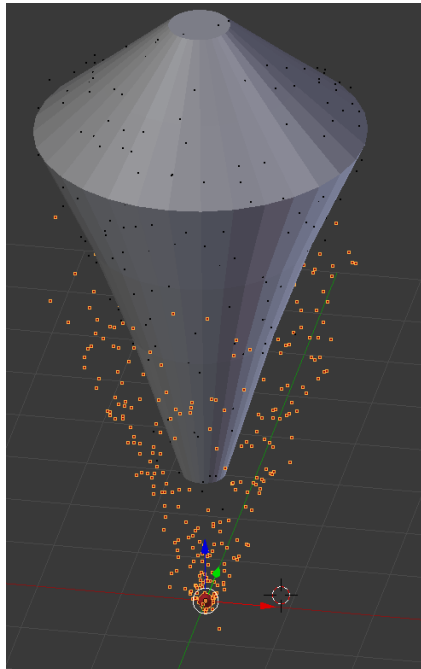
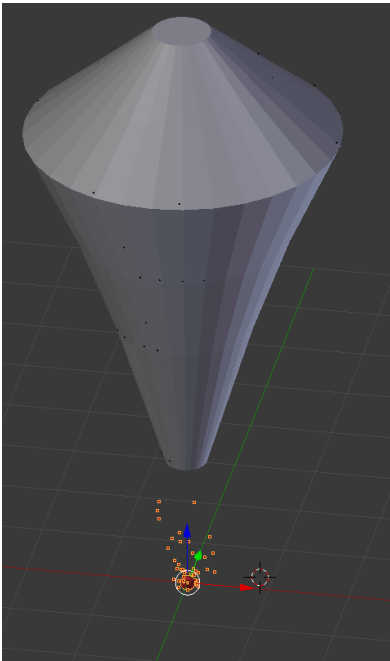
- One emits particles that are rendered, no gravity
- One emits invisible particles
  - From the shape of the mesh
  - No velocity, no gravity
  - Brownian motion
  - Act as attractors for the other particles



## Example contd.



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## Example contd.



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# Particle system control parameters

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## Initial position

- Jittering – amount of randomness

## Spawn rate

- The rate itself
- Changes over time
- All at once, over a certain time, continuously, maximal number of particles, ...

## Initial direction & velocity

- Direction (straight up, sideways, ...)
- Velocity

## Gravity

# Particle system control parameters

## Other forces

- Wind
- Player interaction
- ...

## Time to live

## 2nd and further levels

- Spawn new particles at the end of the life cycle
- E.g. used for fireworks

## Animation

- Control shape, size, transparency, sprite or any other parameter over time







# Rendering Particles

## Billboards

- Textures with (alpha) textures
- Simple geometry (can be instanced)

## Rotating the particles to the camera

- Use the inverse of the view matrix
- View matrix is usually Translation and Rotation
- We only care about the rotation part
  - → Orthogonal matrix, can be inverted by transposing

## Depth-Sorting the particles

- Use the transformed z-value of the particle
- Sometimes not necessary – can be a performance setting

## Trails

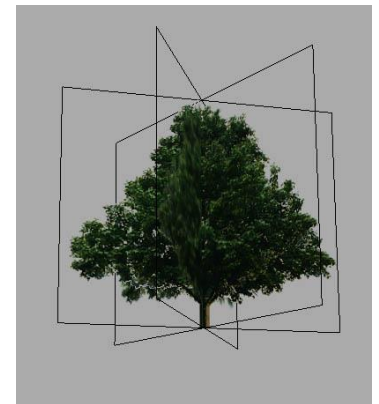
# Types of Billboards

## Quads

- Oriented towards the camera
  - In all directions (e.g. particles)
  - Only in one axis (e.g. vertical objects such as trees)

## Several quads

- Placed around central axes
- E.g. for trees, bushes (vertical)
- Or beams (along the central axis)
- Not oriented towards the camera → one side always visible to a certain degree



# Particle Properties by Reeves

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- (1) initial position,**
- (2) initial velocity (both speed and direction),**
- (3) initial size,**
- (4) initial color,**
- (5) initial transparency,**
- (6) shape,**
- (7) lifetime**



## Example: Fire

**Gravity:** Little to none (fire moves upward)

**Lifetime:** Such that the flames do not rise unrealistically high

**Emission:** Continuously

**Texture:** Simple texture with alpha (to get round look)

### Tint

- Control parameter that can be animated over the lifetime of the particle
- Color value
  - Simple case: Color 1 at birth, Color 2 at death
  - More complicated cases: Provide intermediate key colors
- Supply to shader via a uniform
  - Discard the rgb values of the texture
  - Write the tint-color as rgb and use alpha from the texture

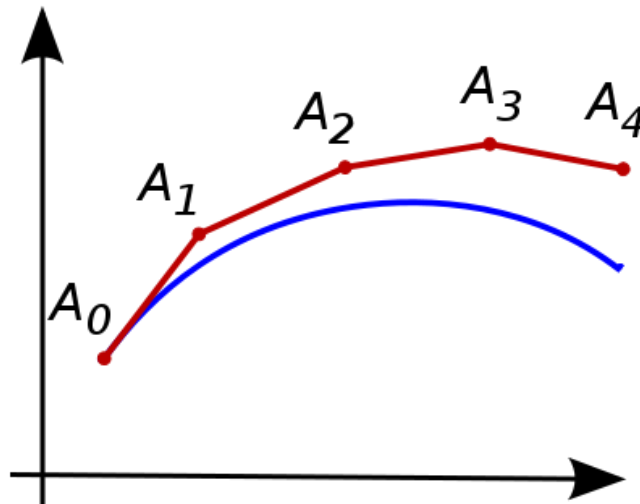
# Integration for particles

**We need to simulate the effect of forces on the particles**

**Closed solution not tractable for real-time interaction and especially player interactions**

## Numerical integration

- Simplest approach: Euler integration



# Apply Newton's second law

Newton's second law:

$$F = m \cdot a$$

$$a = \dot{v}$$

$$v = \dot{x}$$

***F***: force  
***m***: mass  
***a***: acceleration  
***v***: velocity  
***x***: position

By transforming, this can be rephrased as a differential equation for the second derivative of the position, depending on the mass (assumed to be constant) and the force(s) acting on the object at time  $t$ .

$$\ddot{x} = \frac{F}{m}$$



# Solve the differential equation

Usually done numerically

Easiest algorithm: Euler method

First step: Velocity

*t: Previous time*  
 *$\Delta_t$ : Timestep*  
*t +  $\Delta_t$ : Current time*

$$\ddot{x} = \dot{v} = \frac{F}{m}$$
$$v_{t+\Delta_t} = v_t + \frac{F}{m} \Delta_t$$

Second step: Position

$$x_{t+\Delta_t} = x_t + v_t \Delta_t$$

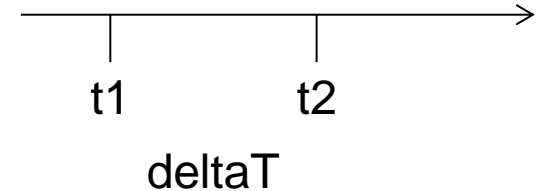




# Time

## With game's frame rate

- Update each frame
- Keep track of the last frame time
- Only an approximation of the next frame's duration
- Watch out for paused game (e.g. tabbed out of the window)



## Independent

- Simulate independent of frame rate
- Sub-frame calculations → more exact
- Can adapt
  - If nothing happens, use large time step
  - Go to important moments (collisions)



# Time source

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## High Precision Event Timer (HPET)

- Found in chipsets starting in 2005
- 64 bit counter
- Counts up with a frequency of at least 10 MHz
- OS sets up an interrupt with a certain frequency

## Getting the time

- Divide the counter value by the frequency
- Watch out for large values (e.g. PC in standby over weeks)

## Solid bodies that do not deform

### Added properties:

- Center of mass
- Rotation
- Angular velocity
- Angular acceleration
- Moment of inertia



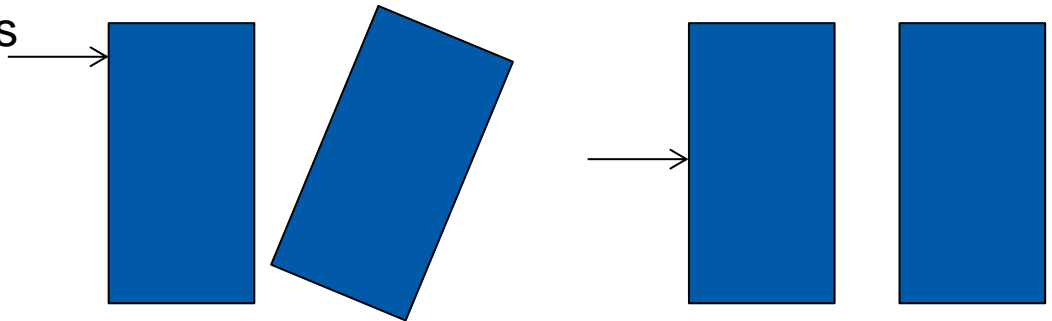
**Mass: The property that resists changes in velocity**

## Center of mass

- Manually: Defined by artist
- Automatically: Assume uniform distribution
  - Integrate over the volume of the body

**Force applied in line with the center of mass change only linear velocity**

- Easiest way to handle collisions
- But not very realistic



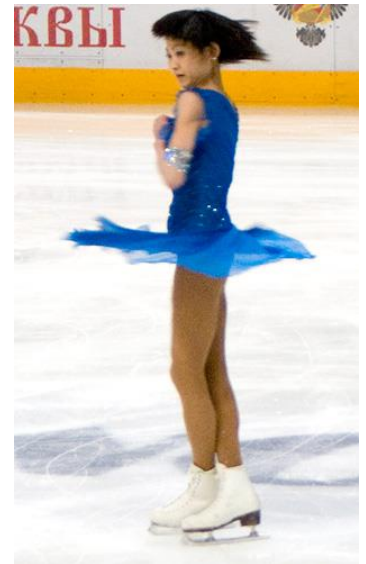
# Moment of Inertia

**Captures the way in which a body resists changes to angular velocity**

**Think of non-uniform objects**

- Pushing at different points leads to different results

**More in the next lecture**

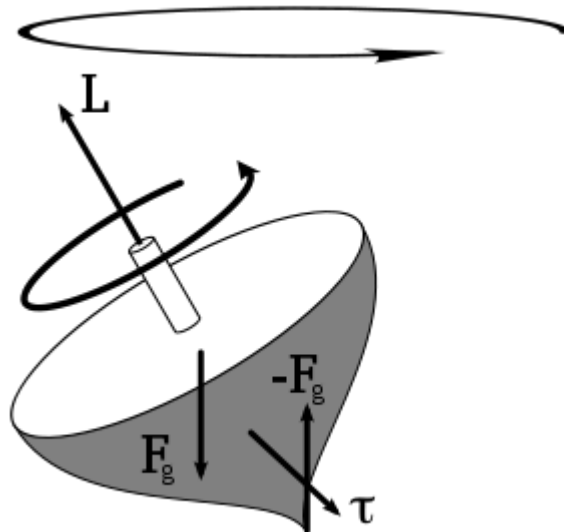


# Torque

~ „Angular acceleration“

Forces that act off the center of balance

More info in next lecture



# Collision Detection

## Information we need to calculate a response:

- Was there a collision?
- What was the collision normal?
- How far are the objects interpenetrating?





# Intersection Sphere-Sphere

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## Easiest intersection

**The spheres intersect if the distance of the centers is less than the sum of the radii**

**Collision normal can be found as the direction of one sphere's center to the other**

**Penetration depth is the difference between the sum of the radii and the center's position**

# Intersection Plane-Sphere

## Describe the plane as

- Normal
- Distance along this normal

$$d = n * c + D$$

## Implicit formula

- Gives us a signed distance
- = 0 everywhere on the surface of the plane
- Distance to the plane everywhere else
- Sign indicates direction (with normal, in the opposite direction)

## Separate objects

- In reality: Elastic collision → energy is absorbed
- Approximate using coefficient of restitution
  - Float between 0 and 1 → indicates the amount of speed retained after the collision
  - $COR = 1$  → No energy lost

## Immovable Objects

- Infinite mass
- Same as inverse mass
  - Needed for calculations this way already
  - Infinite mass → Inverse mass = 0

# Collision between two objects

## Calculate the collision normal

- Direction along which the two objects are colliding
- Plane-Sphere: Use the plane's normal
- Sphere-Sphere (for now): Use the vector from one sphere's center to the other's center

## Calculate the separating velocity

- Velocity with which the objects are colliding plus direction
- Careful with signs
- Velocity  $< 0$ : Colliding
- Velocity  $= 0$ : Resting/Sliding
- Velocity  $= > 0$ : Separating (Nothing to do, yay 😊)

# Collision between two objects

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## Calculate a new separating velocity

- Using the coefficients of restitution and mass of the involved objects

## Calculate an impulse that changes the velocity accordingly

- Instantaneous change in velocity
- In reality: Forces acting over very small times

## Solve the interpenetration

- Move the objects so that they are not colliding any more
- Along the collision normal
- With the aspect ratio of the weights involved
- Immovable object (e.g. ground): Movable object has to move

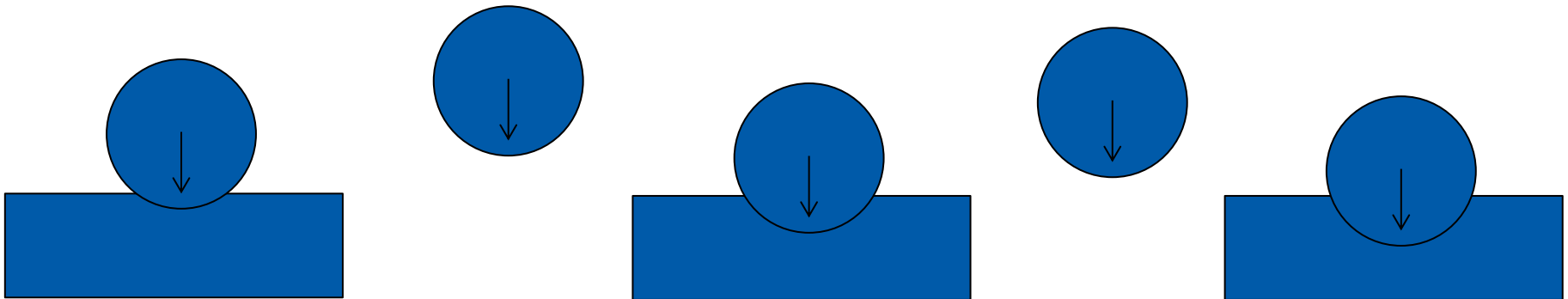
## Apply the impulses

- = Adding to the current velocity

# Problems – Interpenetration

## Ignoring interpenetration

- Just calculate separating velocity
- Objects „hammer“ themselves into the ground
- On each collision, the object settles a bit more into the ground
- → Move the object out of the ground





# Problems - Bouncing

## Reality – Objects do not interpenetrate

- Deformation
- Energy shifted between the materials

## Resting Contact

- Ground supports the resting object
- → Force that counters gravity

## Ways to reduce/eliminate bouncing

- Add an additional impulse to counter the effect of gravity in the next frame
- Put objects to sleep when their energy goes low enough



# Sleeping

## **In many games, most objects will be resting most of the time**

- They only move when a script or a player action causes them to move

## **Identify when objects do not need to be simulated any more**

- Start in a stable position (level design) and sleep initially
- Recognize that the energy is low enough

## **Wake up again**

- Whenever the object takes part in the physical simulation
- Identify „Islands“
  - Groups of objects that should wake up together
  - E.g. the billard balls in the start configuration



# Literature

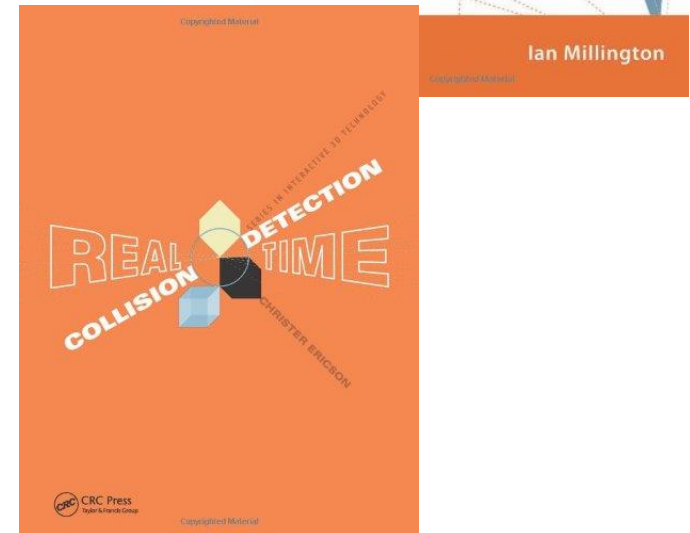
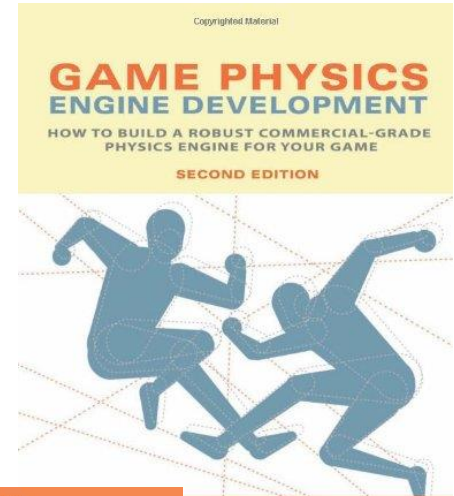


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**“Game Physics Engine  
Development”, Ian Millington**

**“Real-Time Collision Detection”,  
Christer Ericson**

**Box2D blog <http://box2d.org/>**

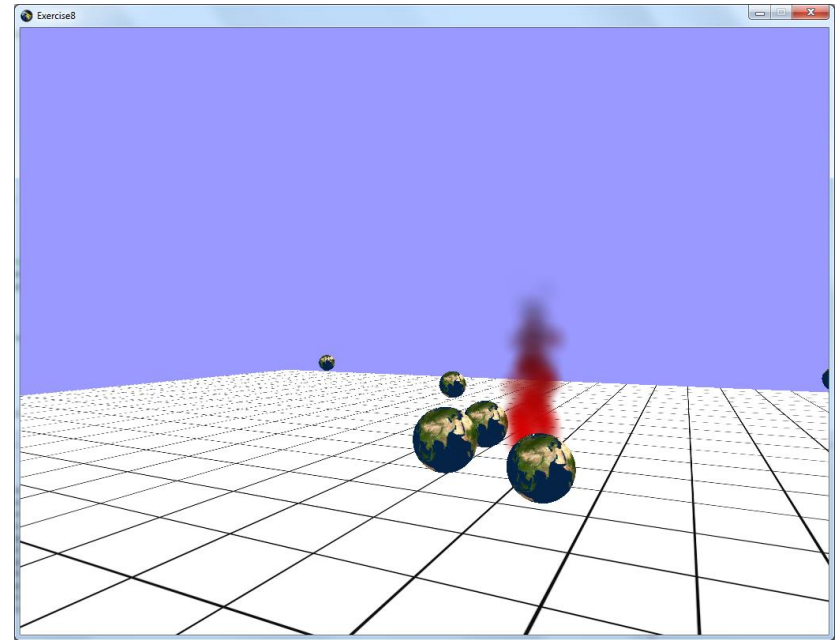


# Exercise

**Will be up after the lecture**

## Particle System

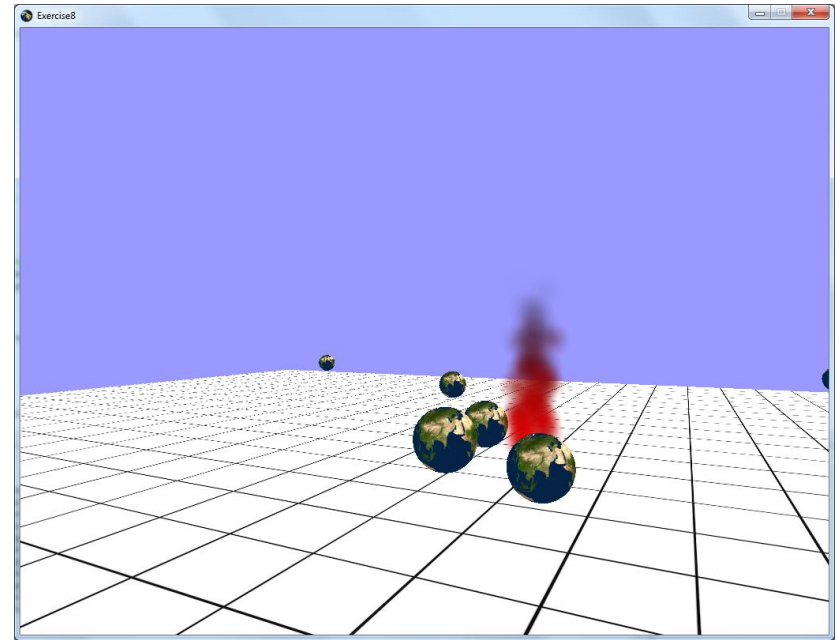
- Orient billboards to the camera
- Implement one new control parameter
  - Free choice of effect
    - Gas
    - Explosion
    - Rain
    - ...
- If you can't think of anything, use the fire example



# Exercise

## Physical Simulation

- Spheres are shot from the camera using Space
- Very simple solution:
  - Bouncing of spheres is not fixed
  - Collision can go horribly wrong ;-)
- We will post a video of the level we are ok with in this exercise



# Questions & Contact



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