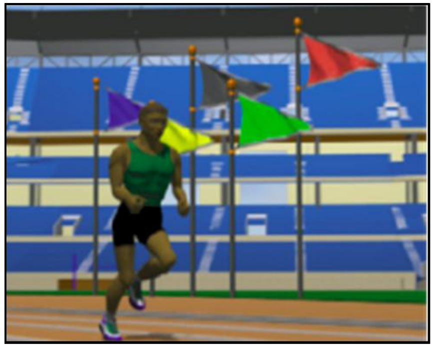
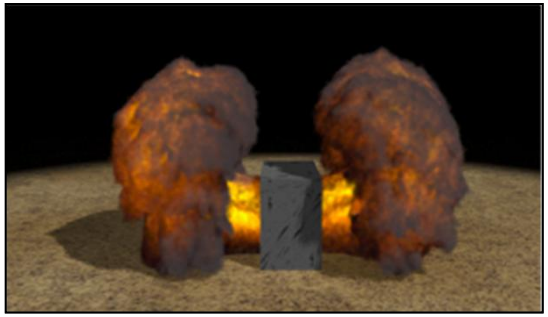
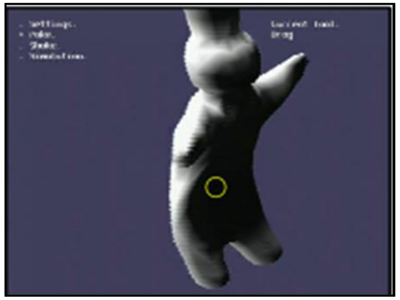
Design of Human Interface Game Software

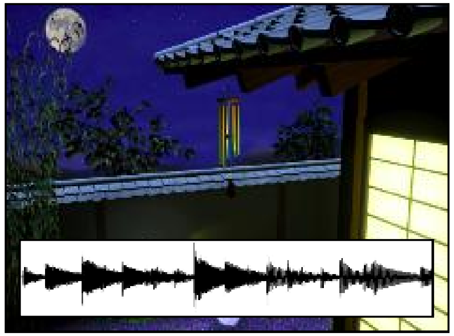
- Physically-Based Animations
- Particle Systems
- Rigid-Body Kinematics

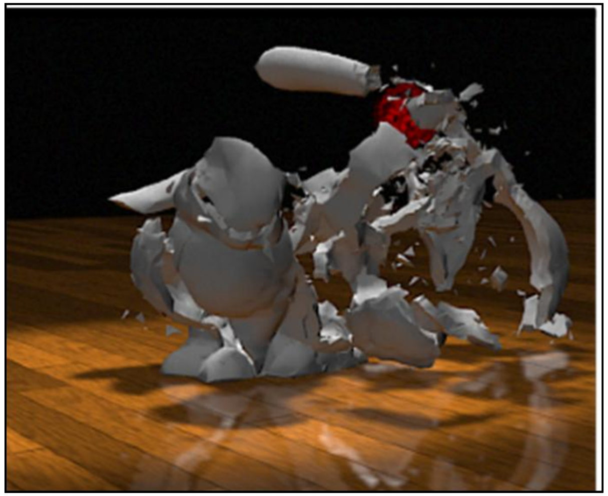
Physically Based Animation

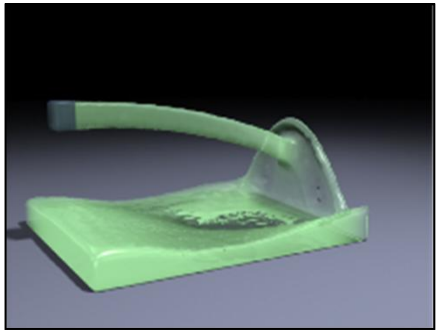


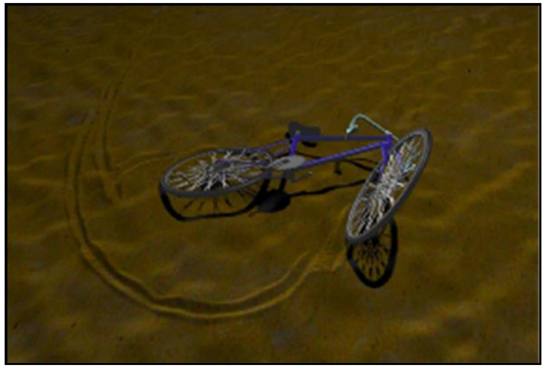












Physically Based Animation in Games

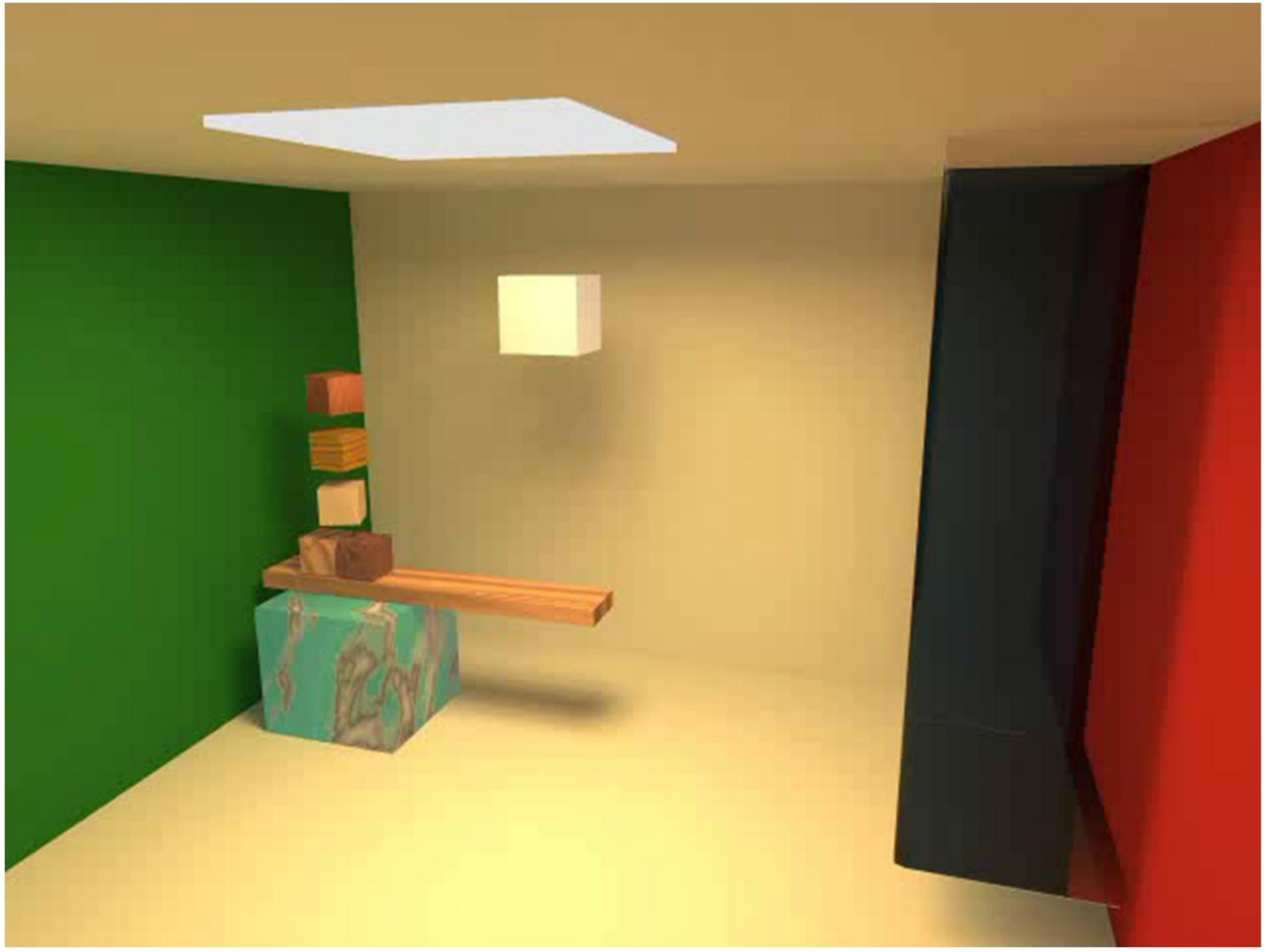
Half Life 2

Max Payne 2

Fuel

Black

Physically-Based Simulation



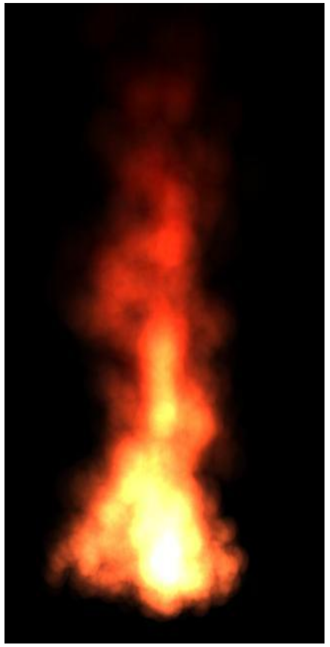
Carlson, Mucha and Turk , SIGGRAPH 2004

Particle Systems

Selle, Rasmussen, and Fedkiw, SIGGRAPH 2005

Representing Objects with Particles

- An object is represented as clouds of primitive particles that define its volume rather than by polygons or patches that define its surface
- A particle system is dynamic, particles changing form and moving with the passage of time
- Object is not deterministic, its shape and form are not completely specified



Particle Systems

- Single particles are very simple
- Large groups can produce interesting effects
- Supplement basic ballistic rules
  - Collisions
  - Interactions
  - Force fields
  - Springs
  - Others…

Feldman *et al*. SIGGRAPH 2005

Karl Sims, SIGGRAPH 1990

Particle Attributes

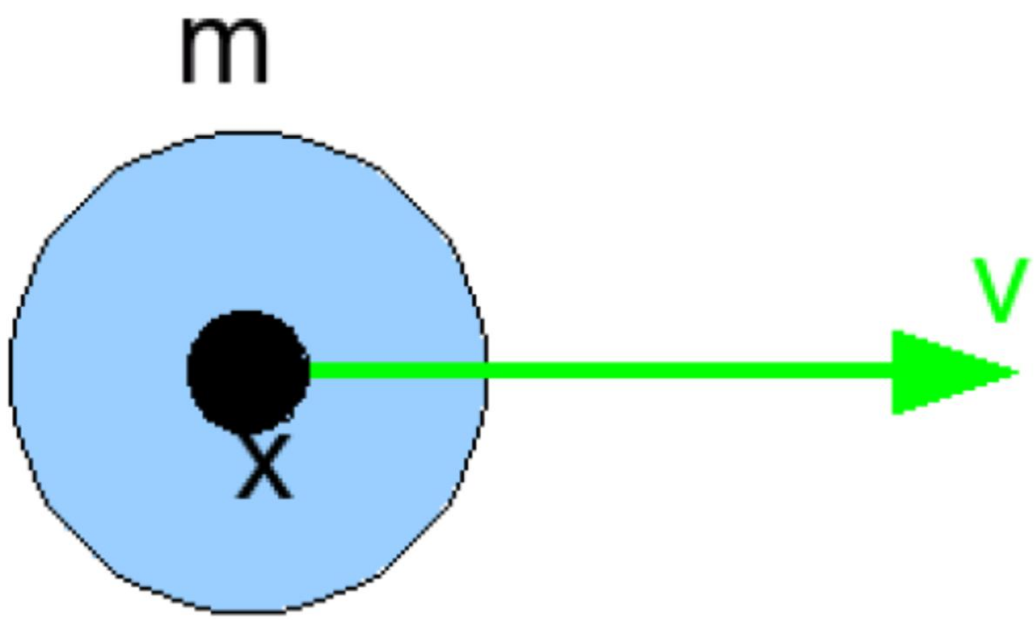
- Initial position
- Initial velocity
- Initial size
- Initial color
- Initial transparency
- Shape
- Lifetime

Basic Model of Particle Systems

1) New particles are generated into the system.
2) Each new particle is assigned its individual attributes.
3) Any particles that have existed past their prescribed lifetime are extinguished.
4) The remaining particles are moved and transformed according to their dynamic attributes.
5) An image of the particles is rendered in the frame buffer, often using special purpose algorithms.

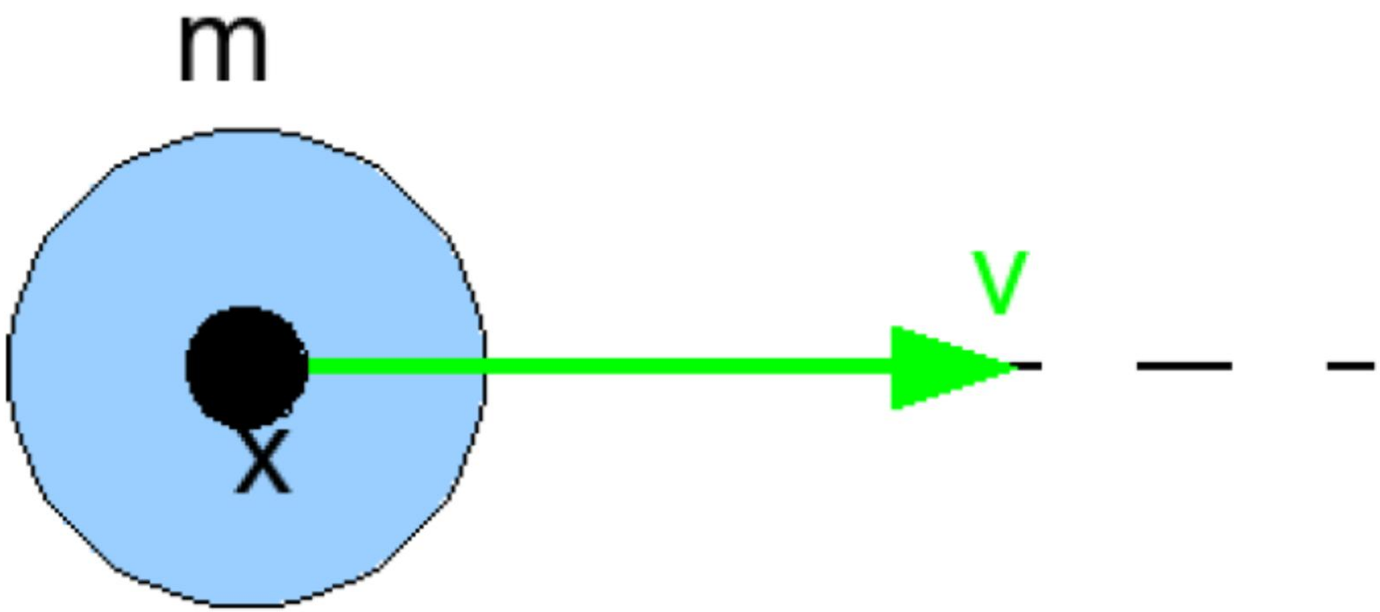
A Physical Particle

- Position x in m
- Velocity $v = \frac{dx}{dt} = \dot{x}$ in m/s
- Mass m in kg



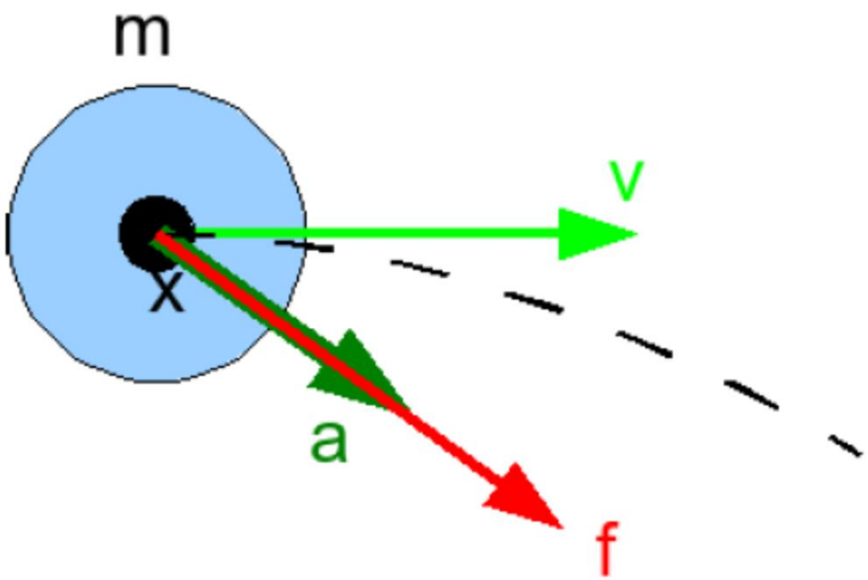
Newton's First Law

- An isolated system has a constant velocity



Newton's Second Law

$$\boxed{f = ma}$$



- Acceleration $a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = \ddot{x}$
- Force in $kg.m/s^2$
- A force is "something" able to modify the trajectory or the shape of an object

Newton's Third Law

$$\boxed{f_{1\to 2} = -f_{2\to 1}}$$

- The net force applied to an isolated system is null, even if internal forces are applied
- Its center of mass has a linear trajectory

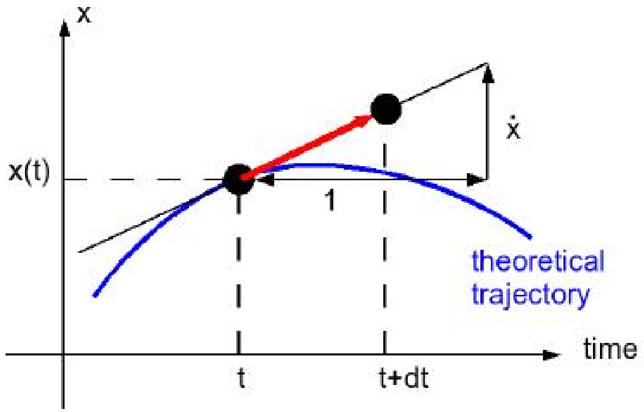
Basic Time Integration

Explicit Euler integration over a time set dt:

- compute acceleration $\ddot{\mathbf{q}}$
- update time, positions and velocities:

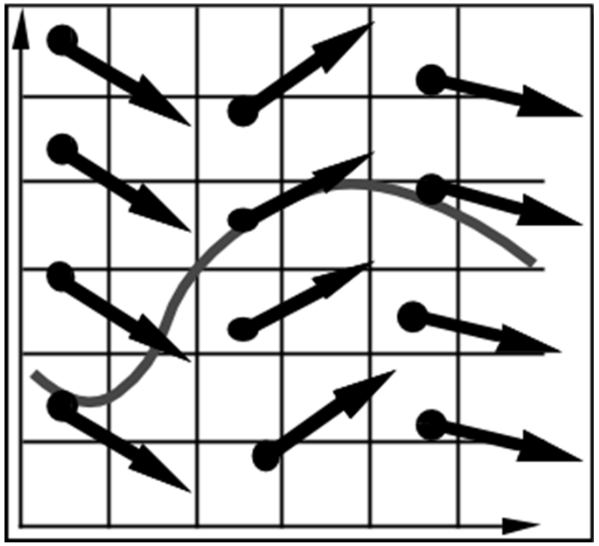
$$\begin{aligned} t &\mathrel{+}= dt \\ \mathbf{q} &\mathrel{+}= \dot{\mathbf{q}} * dt \\ \dot{\mathbf{q}} &\mathrel{+}= \ddot{\mathbf{q}} * dt \end{aligned}$$

- precision depends on dt because update follows the tangent



Vector Fields/Force Fields

- Velocity is determined by a vector field
  or
- Acceleration is determined by a force field

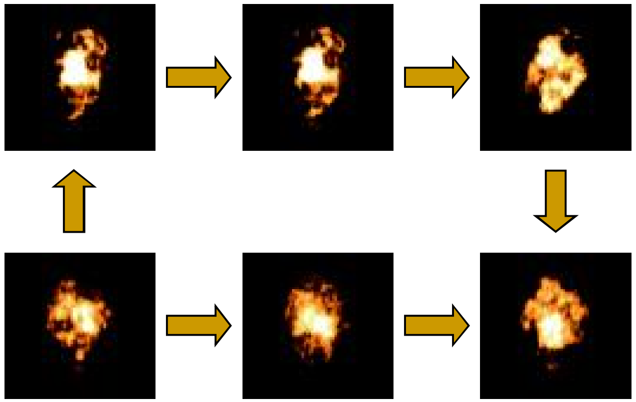


$$Vector\ \ field:\ \dot{x} = g(x,t)$$

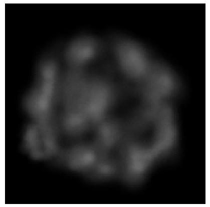
$$Force\ \ field:\ \ddot{x} = \frac{f(x,v,t)}{m}$$

Sprite-Based Particle System

- Particle System
  - Requires too many particles for realism
    ⇒ Takes time!
- Sprite-Based Particle System
  - Animated textures on sprites that move like particles



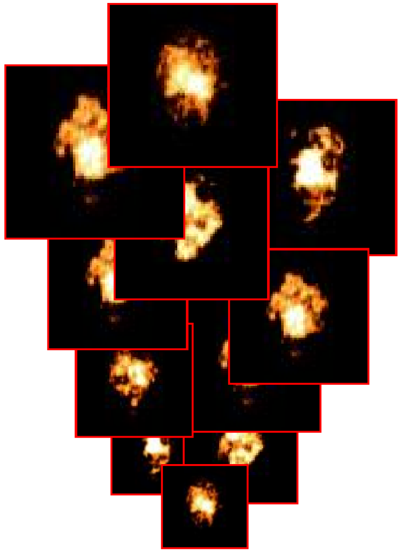
Fire



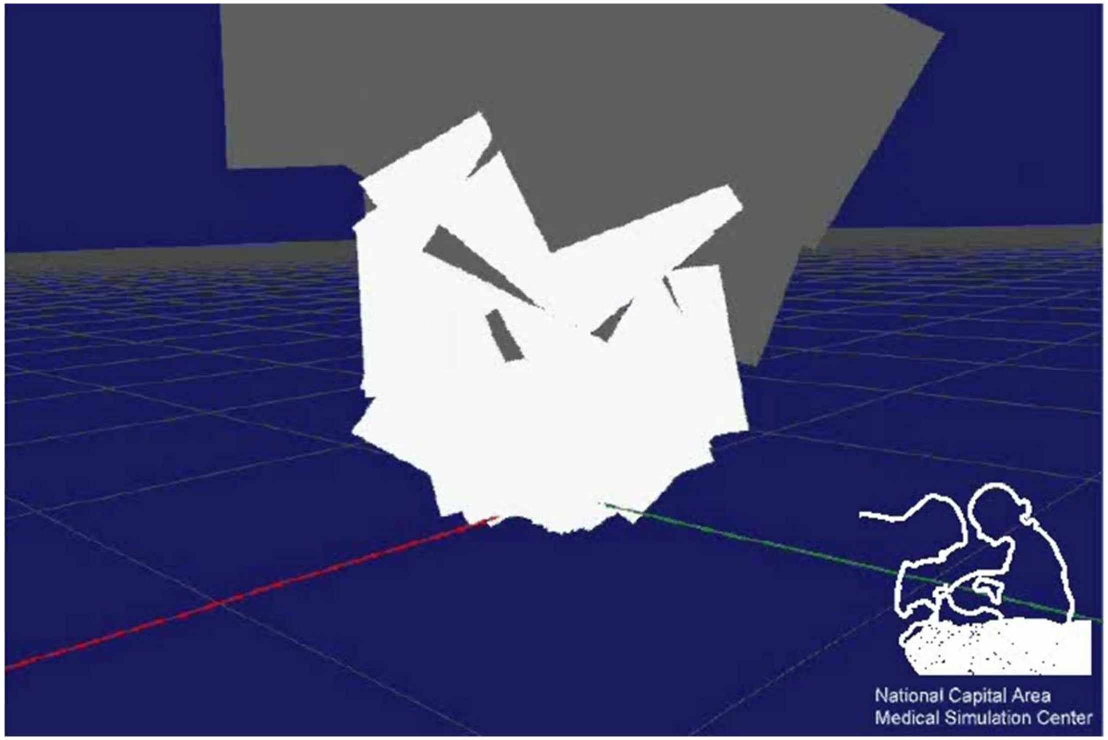
Smoke

Sprite-Based Particle System

- Sprites are generated, moved, and removed
- Animated textures are displayed on each sprite
- Sprites are billboarded (face to the eye)
- Blended with background



Sprites with textures





Rigid-Body Kinematics

Basic Concepts

- Kinematics

  : The study of motion. How does acceleration affect velocity? How does velocity affect position?

  - Particles: A point-mass. Rotation ignored.
    Position, velocity
  - Rigid Body: Rotation of the body considered.
    Position+orientation, velocity+angular velocity

Basic Concepts

- Force: Objects change motion only when forces are applied
  - Contact/field forces: gravity, magnetism, hit
  - Torque: rotational forces
  - Environmental sources: Friction, buoyancy
- Non-rigid Objects
  - Joints and constraints: mass-spring systems
  - Flexible objects: cloth, hair

Game Physics

- Projectiles: eg) bullets, cannon balls
  - Body rotation may be negligible
  - Effects due to gravity, wind, air resistance
- Aircraft: eg) flight simulators
  - Full 3D motion modeling
  - Effects due to lift(양력), drag(유체저항), turbulence
  - Control issues
- Cars: eg) racing games
  - Friction, road resistance, breaking, skidding
  - Effects of road banking
  - Crashing/tumbling

Newton's Laws

- Newton's Laws of Motion
  - Law I: An object tends to remain at rest or continue to move at constant velocity, unless it is acted upon by an external force (Inertia)
  - Law II: Force equals mass multiplied by acceleration (F=ma)
  - Law III: For every action there is an equal and opposite reaction (action-reaction)

Rigid Bodies

- Rigid Bodies
  - No moving parts, no flexibility
  - Need to consider rotation unlike particles
  - Simple to analyze/model
- Properties
  - Mass
  - Center of mass

Speed and Velocity

Speed and Velocity:

Average Speed: Let s denote the object's position and t denote time. Assuming motion along a line, speed is the change in **position** Δs over some **time interval** Δt.

$$v = \frac{\Delta s}{\Delta t}$$

Instantaneous speed: If speed varies with time, we need to consider the limit for **differential** (infinitely small) time intervals:

$$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

Velocity: Is a **vector-valued** quantity, whose **magnitude is the speed** and whose direction indicates the **direction of motion**. (We will sometimes be sloppy and refer to speed as "velocity".)

Acceleration

Acceleration: Change in speed over time.

Average Acceleration: Change in **speed** Δv over some **time** Δt.

$$a = \frac{\Delta v}{\Delta t}$$

Instantaneous acceleration: If speed varies with time, we need to consider the limit for **differential** (infinitely small) time intervals:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

Example: A car goes from 0 to 60 m/h in 4.2 seconds. The average acceleration in ft/s^2 is:

$$a = \frac{\Delta v}{\Delta t} = \frac{60\frac{m}{h}}{4.2s} = \frac{60\frac{m}{h} \cdot \frac{1h}{3600s} \cdot \frac{5280f}{m}}{4.2s} = \frac{60 \cdot 5280f}{4.2 \cdot 3600s^2} \approx 21\frac{f}{s^2}$$

Relationships

Relating Position, Velocity, and Acceleration:

Position and Velocity: By definition, $v(t) = ds/dt$. Suppose that an object moves from position s_0 to s_1 during the time period t_0 to t_1. We have:

$$ds = v(t)\,dt$$

$$\int_{s_0}^{s_1} ds = \int_{t_0}^{t_1} v(t)\,dt$$

$$\Delta s = s_1 - s_0 = \int_{t_0}^{t_1} v(t)\,dt$$

We will often drop the parameter t and just write "v" here.

Velocity and Acceleration: By similar argument we have:

$$\Delta v = v_1 - v_0 = \int_{t_0}^{t_1} a(t)\,dt$$

All three: We also have:

$$a = dv/dt = d^2s/dt^2 \quad \text{and} \quad v\,dv = a\,ds$$

Constant acceleration

Constant Acceleration: What is the position, as a function of time, of an object moving with **constant acceleration** a?

Start: At time $t_0 = 0$ the object is at position s_0 with velocity v_0.

Question: At time $t \geq 0$, what is the **object's position**, $s(t)$?

Analysis: We observed earlier that:

$$\Delta v = v_1 - v_0 = \int_{t_0}^{t_1} a\,dt \quad \text{that is} \quad v(t) - v_0 = \int_0^t a\,dt$$

Since acceleration is constant this yields $\boxed{v(t) = v_0 + a \cdot t.}$ Using the fact that $v\,dt = ds$, we have:

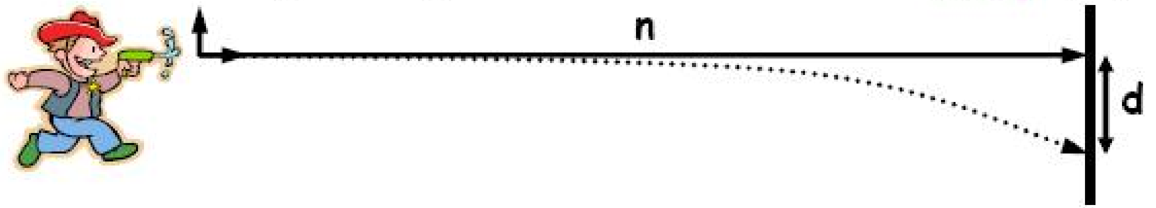
$$\int_{s_0}^{s(t)} ds = \int_0^t v(t)\,dt = \int_0^t (v_0 + at)\,dt$$

$$s(t) - s_0 = \left[v_0 t + \frac{at^2}{2} \right]_0^t = v_0 t + \frac{at^2}{2}$$

$$\boxed{s(t) = s_0 + v_0 t + \frac{at^2}{2}}$$

Example: Bullet Trajectory

Bullet Trajectory: We shoot a bullet from the **origin** along the +x axis to a target at **distance n**. Muzzle velocity is v_m. Assuming no wind resistance, how far does the bullet **drop** (d) due to gravity?



Along x: x-velocity is constant: $v_x = v_m$; $a_x = 0$; $s_x(t) = v_m\, t$.

- **Hit time** t_h satisfies: $n = s_x(t_h) = v_m \cdot t_h$. So, $t_h = n/v_m$.

Along y: y-velocity starts at $v_y(0) = 0$, but is subject to **gravitational acceleration**: $g \approx 32\text{ft/s}^2 \approx 9.8\text{m/s}^2$.

- $a_y = -g$.
- $v_y(t) = v_y(0) + a_y\, t = -g \cdot t$.
- $s_y(t) = s_y(0) + v_y(0) \cdot t + a \cdot t^2/2 = -g \cdot t^2/2$.
- Plugging in t_h yields: $d = s_y(t_h) = -g \cdot t_h^2/2 = \boxed{-g \cdot n^2/(2v_m^2)}$.

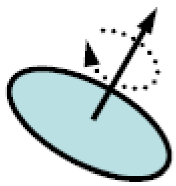
Angular Velocity

Rigid Body Rotation:

- So far we have only discussed **translation**, which would be fine if all objects were treated as **particles** (point-mass).
- For a complete understanding, we must consider **rotation**.
- Rotation occurs about:
  - the object's **center of mass** and
  - some **axis of rotation** (which may change depending on forces).

Plane Kinematics:

- All rotation occurs about a **fixed axis of rotation** in 3-space. (I.e, on a plane orthogonal to that axis.)



- Good enough for many $2\frac{1}{2}$-dimensional games (e.g. Super Mario 64).

General Kinematics:

- 3D rotation: **Euler angles** and **quaternions**

Angular Velocity

Each of the principal quantities for translational motion has its counterpart in angular motion.

Translational Motion			Angular Motion		
Quantity	Symbol	Dims.	Quantity	Symbol	Dims.
Position	s	L	Angle of orientation	Ω	radians
Velocity	v	L/T	Angular velocity	ω	radians/s
Acceleration	a	L/T^2	Angular acceleration	α	radians/s^2