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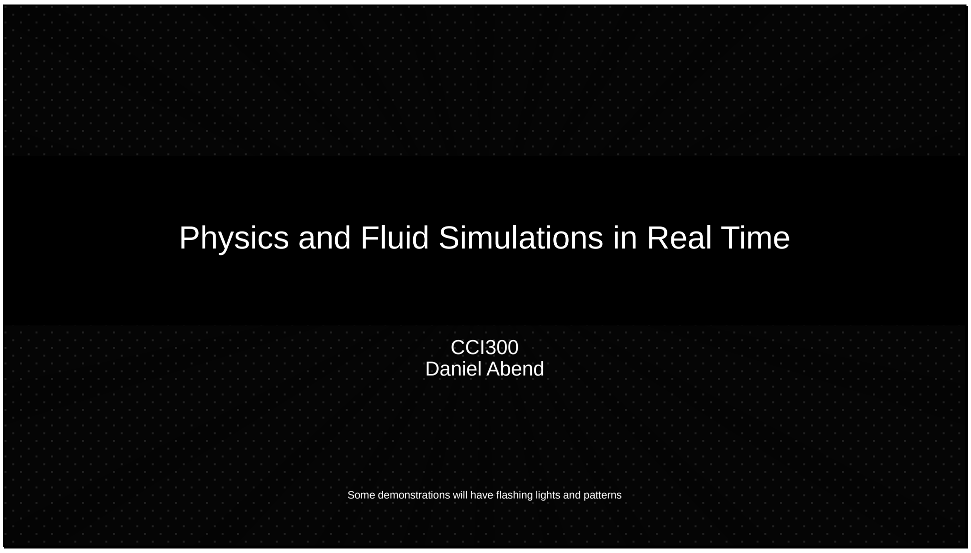


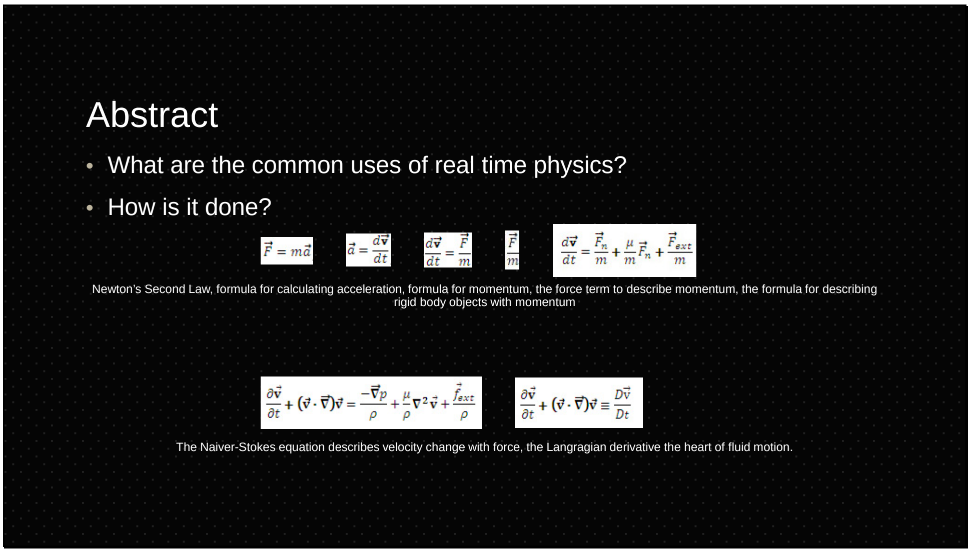
Physics and Fluid Simulations in Real Time

CCI300
Daniel Abend

Some demonstrations will have flashing lights and patterns

Welcome to my lecture on Physics and Fluid Simulations in Real Time

Slide 2



Abstract

- What are the common uses of real time physics?
- How is it done?

$\vec{F} = m\vec{a}$ $\vec{a} = \frac{d\vec{\mathbf{v}}}{dt}$ $\frac{d\vec{\mathbf{v}}}{dt} = \frac{\vec{F}}{m}$ $\frac{\vec{F}}{m}$ $\frac{d\vec{\mathbf{v}}}{dt} = \frac{\vec{F}_n}{m} + \frac{\mu}{m}\vec{F}_n + \frac{\vec{F}_{ext}}{m}$

Newton's Second Law, formula for calculating acceleration, formula for momentum, the force term to describe momentum, the formula for describing rigid body objects with momentum

$\frac{\partial\vec{\mathbf{v}}}{\partial t} + (\vec{\mathbf{v}} \cdot \vec{\nabla})\vec{\mathbf{v}} = \frac{-\vec{\nabla}p}{\rho} + \frac{\mu}{\rho}\nabla^2\vec{\mathbf{v}} + \frac{\vec{f}_{ext}}{\rho}$ $\frac{\partial\vec{\mathbf{v}}}{\partial t} + (\vec{\mathbf{v}} \cdot \vec{\nabla})\vec{\mathbf{v}} \equiv \frac{D\vec{\mathbf{v}}}{Dt}$

The Naiver-Stokes equation describes velocity change with force, the Langragian derivative the heart of fluid motion.

Different types of physics are used for collision detection for impacts, stop actors from walking through walls and simulating gravity, clothing and hair.

It uses a physics engine within the real time platform, some common engines are Nvidia's PhysX and Havok Physics. These engines use algorithms to simulate the classical mechanics or Newtonian Physics as well as more complex fluid mechanics that make use of the Navier-Stokes equations that is comparable to Newtons equations of motion.

For a rigid body, the governing equations include Newton's second law of motion, describing how its velocity changes direction and speed over time. Fluids are more complicated and have more than one set of governing equations. In addition, each set of equations has multiple forms, which can vary depending on what kind of fluid you want to model.

Modelling a fluid entails more than just its motion: You can also model its internal state (pressure, density, and temperature), heat transport, and other properties.

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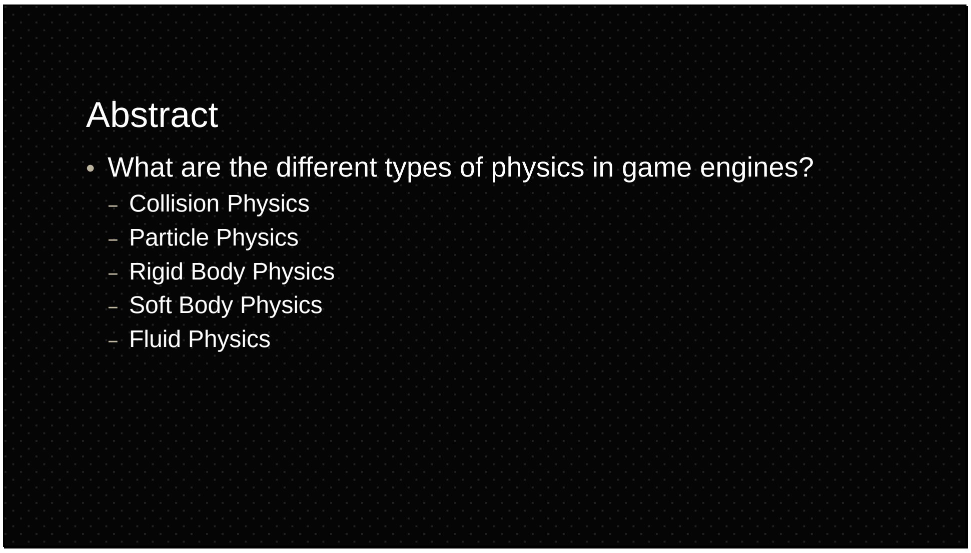

Abstract

- What are the different types of physics in game engines?
  - Collision Physics
  - Particle Physics
  - Rigid Body Physics
  - Soft Body Physics
  - Fluid Physics

Collision Physics - checks for every game tick, whether an actor is colliding with another actor. This collision detection can initiate a collision response. A collision response defines the action taken when an actor collides with another actor during gameplay.

Particle Physics - are points that have position, mass, and velocity but no size or shape. The relationship between forces and motion is linear. Particles are easy to simulate.

Rigid Body Physics - have shape and orientation in addition to position, mass, and velocity. If you add "shape" to a particle, you get a rigid body.

Soft Body Physics - can change shape but the edges between vertices never change which vertices they connect to, but the locations of the vertices can move.

Fluid Physics - The motion is nonlinear and their shape and topology can change. Fluids require specialized simulation techniques: Because fluids take the shape of their container, they are always in collision with everything around them, including the fluid itself. So a collision with one part of the fluid effectively means that the whole body of fluid must respond.

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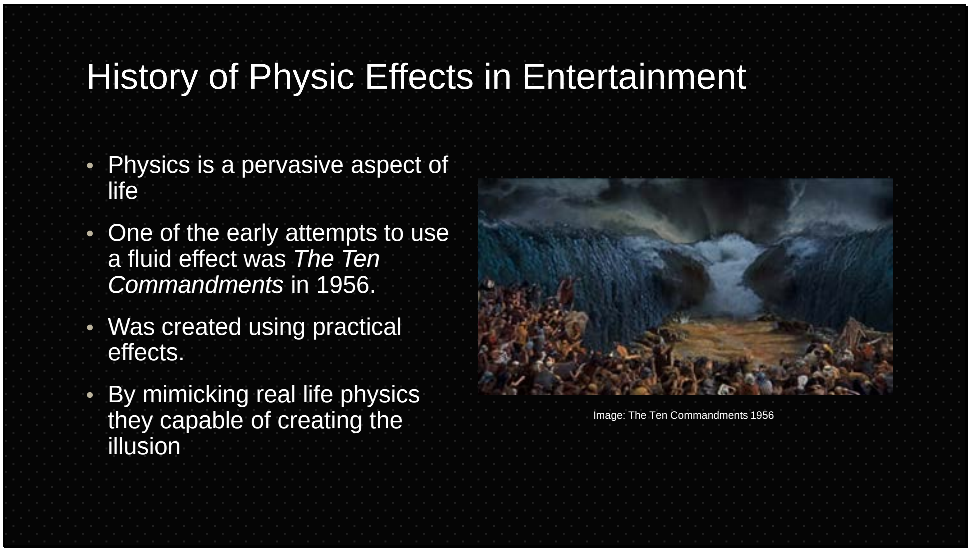

History of Physic Effects in Entertainment

- Physics is a pervasive aspect of life
- One of the early attempts to use a fluid effect was *The Ten Commandments* in 1956.
- Was created using practical effects.
- By mimicking real life physics they capable of creating the illusion

Image: The Ten Commandments 1956

Physics is an everyday aspect.

Attempts to create fluid effects in entertainment have been around for a long time. One of the more impressive fluid effects was in the Ten Commandments in 1956 where

John Fulton and Paul Lerpae used practical water elements to composite an otherwise impossible shot of the red sea parting.

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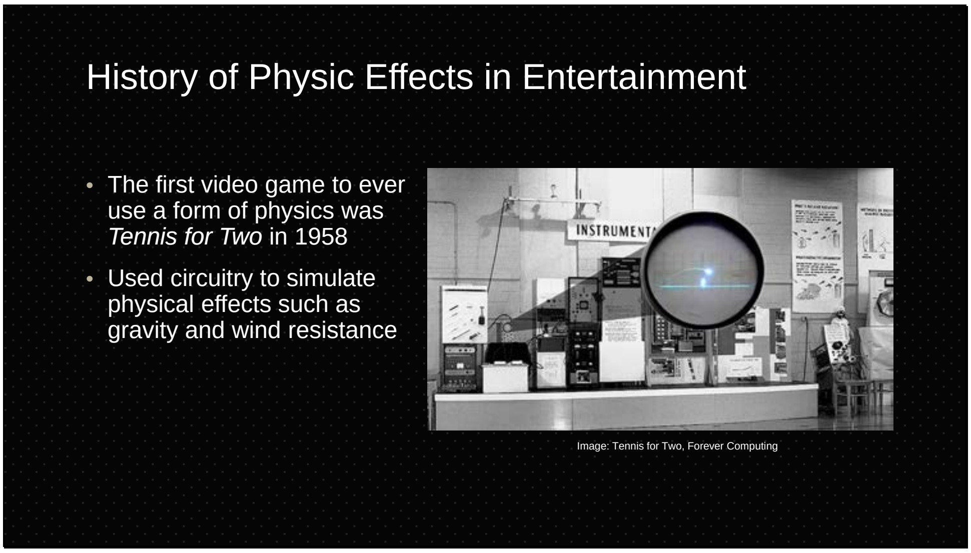


History of Physic Effects in Entertainment

- The first video game to ever use a form of physics was *Tennis for Two* in 1958
- Used circuitry to simulate physical effects such as gravity and wind resistance

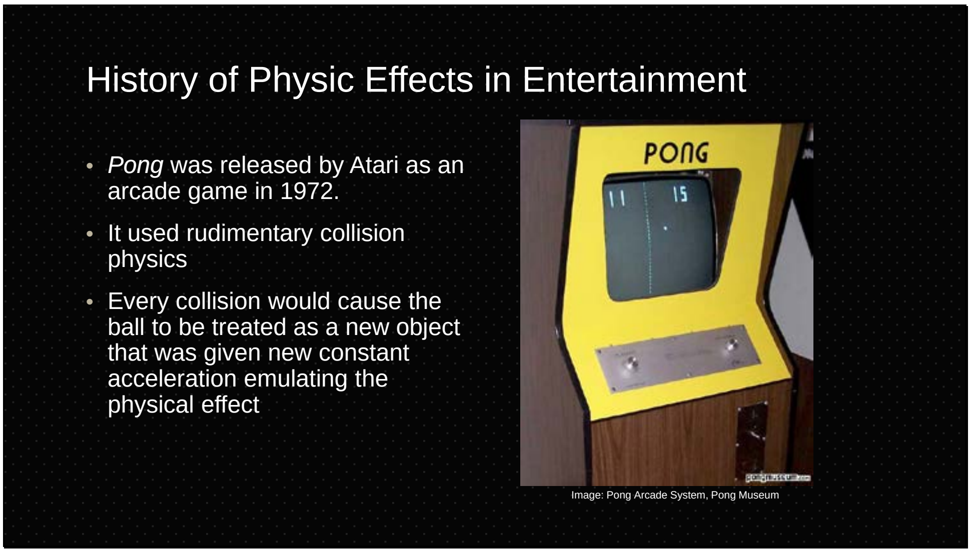
Image: Tennis for Two, Forever Computing

The first video game to ever use physics was Tennis for Two in 1958. it was invented by the physicist William Higginbotham.

The game featured a horizontal line for the ground, a vertical line for a net and a point for the ball. Using only transistors and circuitry, Tennis for Two featured limited gravity effects on the ball which could vary based on what planet the player selected and wind resistance.

This dot here in the picture is the Oscilloscope used for display.

Slide 6



History of Physic Effects in Entertainment

- *Pong* was released by Atari as an arcade game in 1972.
- It used rudimentary collision physics
- Every collision would cause the ball to be treated as a new object that was given new constant acceleration emulating the physical effect

Image: Pong Arcade System, Pong Museum

In 1972 Pong was released.

Pong was the most advanced of its time, requiring calculations coded into the circuitry of the system to direct the ball between the player controlled paddles.

The player controlled paddles and border walls would invoke a collision response upon the ball for every instance where the ball hit either objects.

Every collision would cause the ball to be treated as a new object that was given new constant acceleration emulating the physical effect.

The physics involved were simplified to emulated the effect rather than the cause

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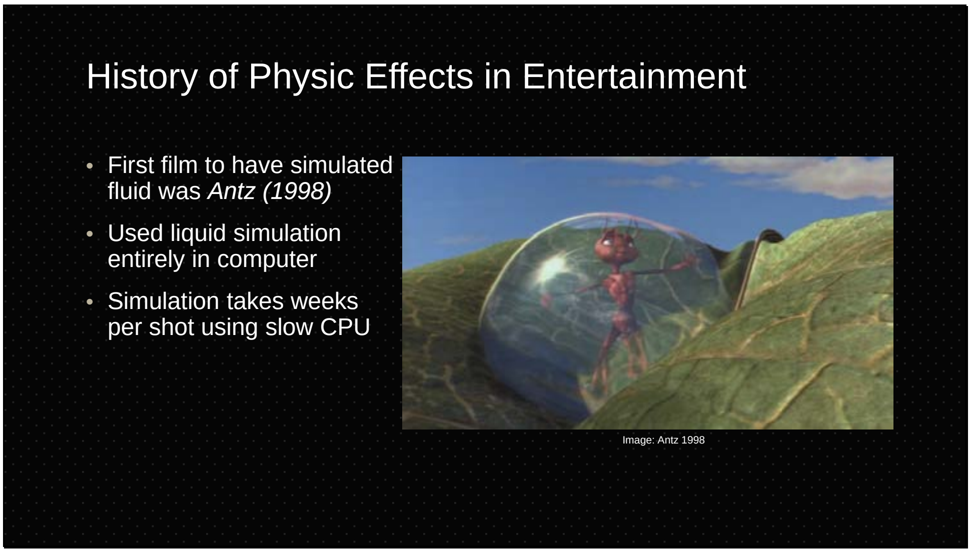

History of Physic Effects in Entertainment

- First film to have simulated fluid was *Antz (1998)*
- Used liquid simulation entirely in computer
- Simulation takes weeks per shot using slow CPU

Image: Antz 1998

It wasn’t until 1998 and the release of DreamWorks Antz that we saw completely computer simulated fluids.

Simulation of fluids traditionally take a long time.

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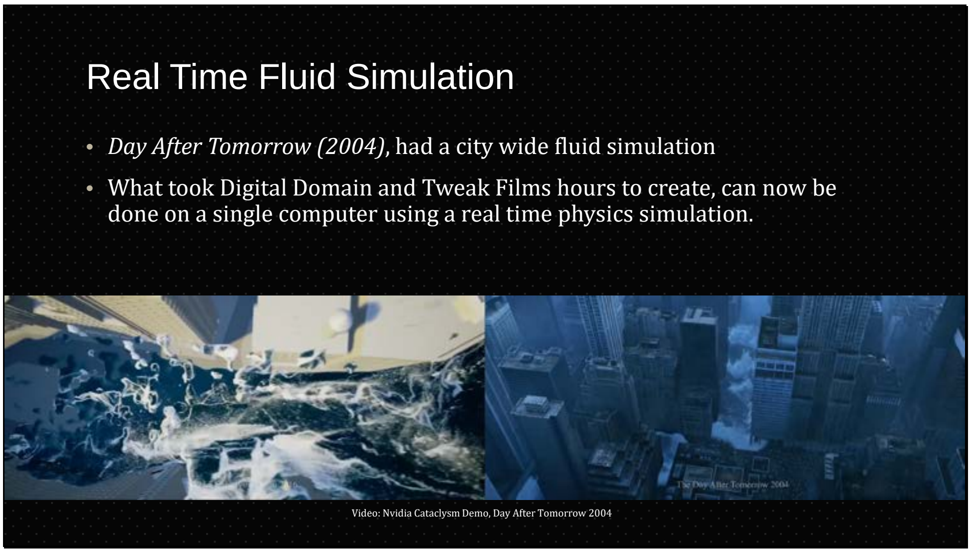

Real Time Fluid Simulation

- *Day After Tomorrow (2004)*, had a city wide fluid simulation
- What took Digital Domain and Tweak Films hours to create, can now be done on a single computer using a real time physics simulation.

Video: Nvidia Cataclysm Demo, Day After Tomorrow 2004

From Antz in 1998 we move to The Day After Tomorrow in 2004, which featured New York being flooded by a giant wall of water.

This scene took two production houses, Digital Domain and Tweak films anywhere between two and three hours per frame per machine to simulate.

This year, Nvidia released a FLIP (Fluid-Implicit Particle) solver for Unreal Engine which can simulate up to two million fluid particles in real time. It is a hybrid system that uses grid and particle techniques that we will talk about later on.

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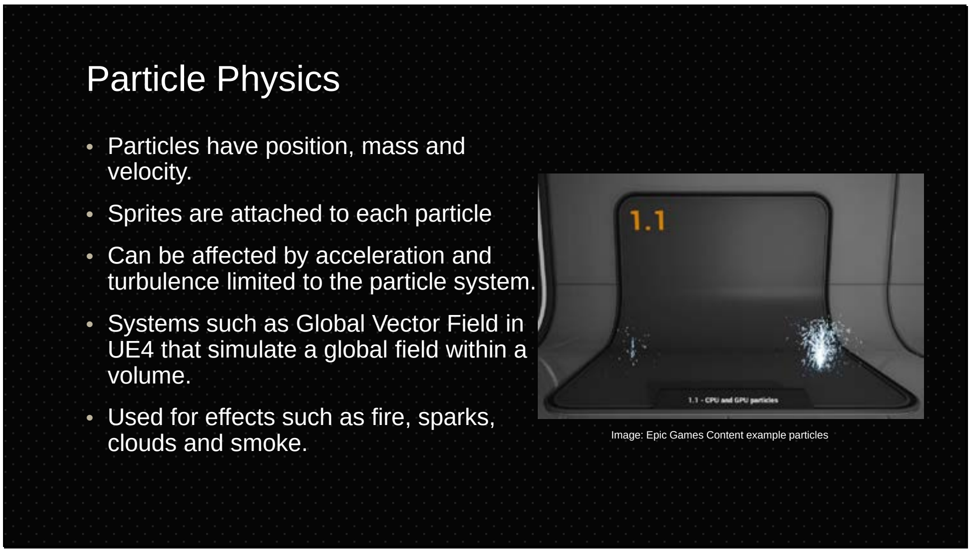

Particle Physics

- Particles have position, mass and velocity.
- Sprites are attached to each particle
- Can be affected by acceleration and turbulence limited to the particle system.
- Systems such as Global Vector Field in UE4 that simulate a global field within a volume.
- Used for effects such as fire, sparks, clouds and smoke.

Image: Epic Games Content example particles

Before we look at fluid physics, we need to understand more simple physics first.

Particles are points that have position, mass, and velocity but no size or shape. Sprites are attached to each point and assigned a material that usually uses flipbook animated textures to create the illusion of shape and size.

Particles can be affected by various forces within their own emitter, not global forces.

There are work arounds in many game engines like the Global Vector Field in Unreal Engine that affects particles that move within the volume of the vector field.

They are generally used for simple effects such as fire, sparks, clouds and smoke.

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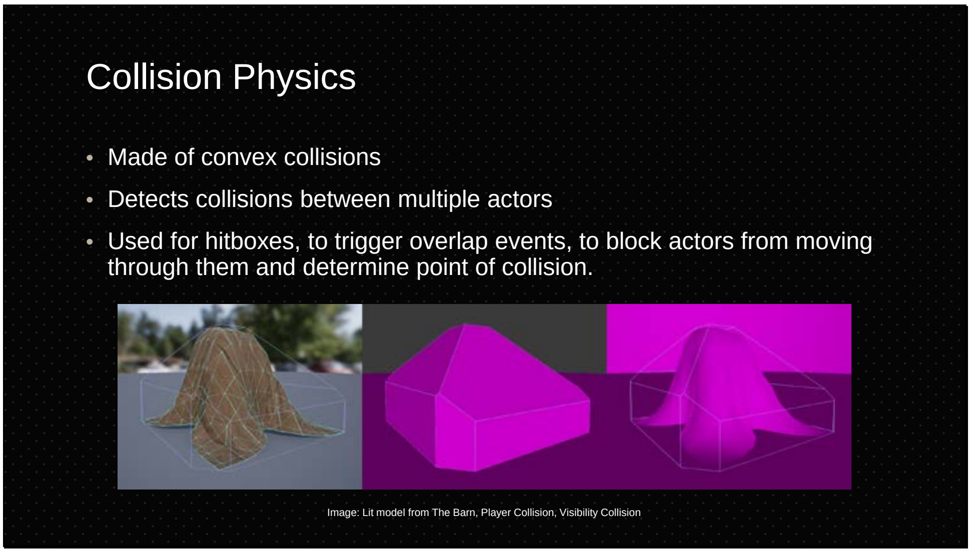

Collision Physics

- Made of convex collisions
- Detects collisions between multiple actors
- Used for hitboxes, to trigger overlap events, to block actors from moving through them and determine point of collision.

Image: Lit model from The Barn, Player Collision, Visibility Collision

Collisions are made of collision bounds of an object, these are volumes that defines the physics outline of the object. These are generally less accurate than the mesh of the object to reduce the processing requirements.

Every object that can collide is defined by an object type definition and a series of collision responses that define how it interacts will all other object types. When a collision or overlap event occurs, both (or all) objects involved can be set to affect or be affected by blocking, overlapping, or ignoring each other.

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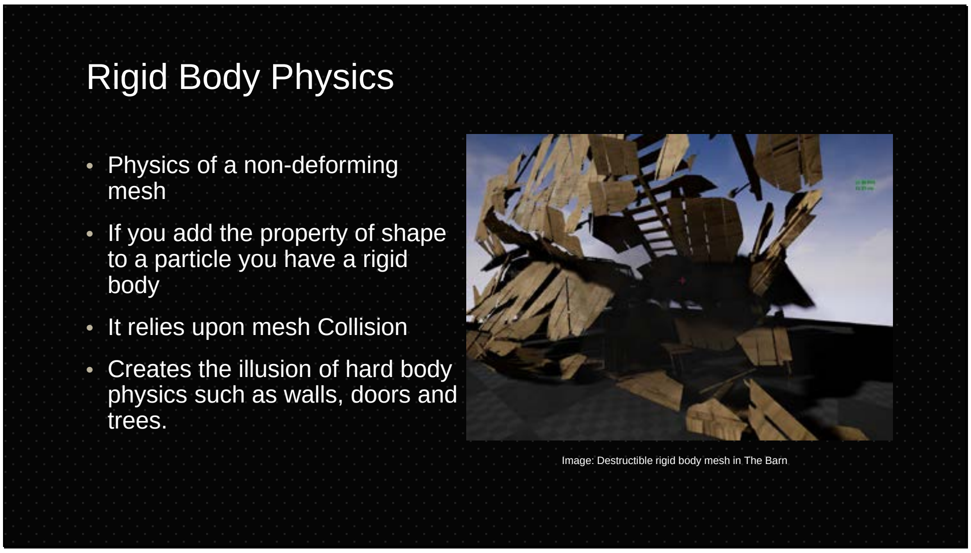

Rigid Body Physics

- Physics of a non-deforming mesh
- If you add the property of shape to a particle you have a rigid body
- It relies upon mesh Collision
- Creates the illusion of hard body physics such as walls, doors and trees.

Image: Destructible rigid body mesh in The Barn

Rigid bodies are unable to change their shape when under force.

If you add "shape" to a particle, you get a rigid body.

Rigid bodies are still easy to simulate: Most of the difficulty comes from detecting and responding to collisions. Stacks of bodies are usually the most difficult to solve, because everything in the stack continuously collides with everything else in the stack-even if nothing moves

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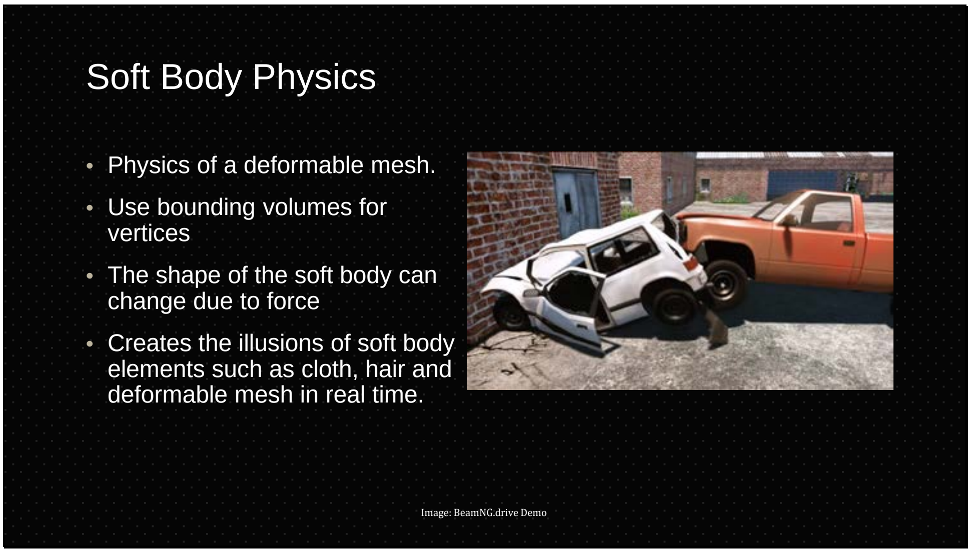

Soft Body Physics

- Physics of a deformable mesh.
- Use bounding volumes for vertices
- The shape of the soft body can change due to force
- Creates the illusions of soft body elements such as cloth, hair and deformable mesh in real time.

Image: BeamNG.drive Demo

Soft bodies are deformable bodies

Soft bodies are defined by an object bounds. If force is applied to the bounds then the object is deformed and given acceleration resulting in the relative distance between two points not being fixed like in rigid bodies.

Soft bodies are used for cloth, hair, organic tissue and sometimes a less expensive fluid substitute.

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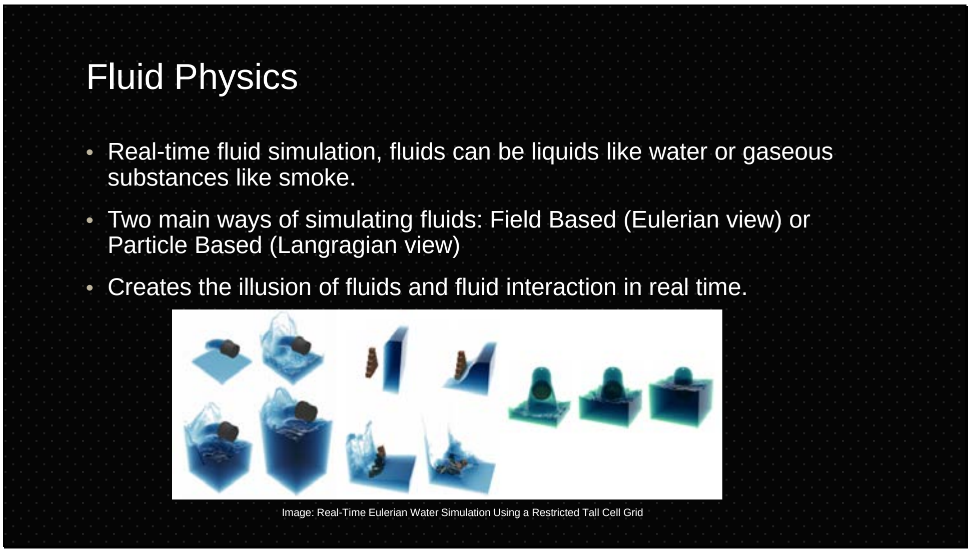


Fluid Physics

- Real-time fluid simulation, fluids can be liquids like water or gaseous substances like smoke.
- Two main ways of simulating fluids: Field Based (Eulerian view) or Particle Based (Langragian view)
- Creates the illusion of fluids and fluid interaction in real time.

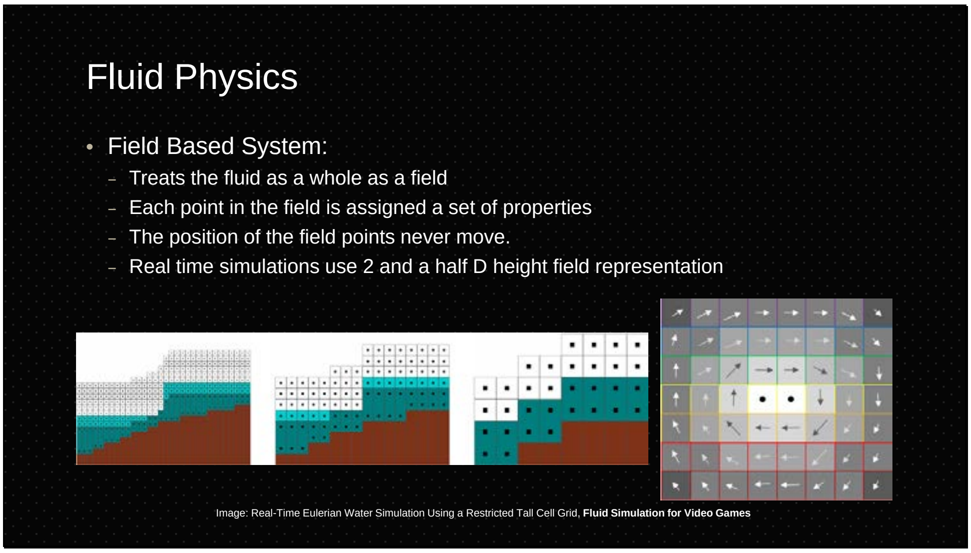
Image: Real-Time Eulerian Water Simulation Using a Restricted Tall Cell Grid

This brings us to the current real time platform challenge, fluid simulation.

Fluids require specialized simulation techniques: Because fluids take the shape of their container, they are always in collision with everything around them, including the fluid itself. So a collision with one part of the fluid effectively means that the whole body of fluid must respond.

Fluids can describe any physical effect that assumes the shape of its container, this could be a gas, liquid or a combination of the two such as steam.

Slide 14



Fluid Physics

- Field Based System:
  - Treats the fluid as a whole as a field
  - Each point in the field is assigned a set of properties
  - The position of the field points never move.
  - Real time simulations use 2 and a half D height field representation

Image: Real-Time Eulerian Water Simulation Using a Restricted Tall Cell Grid, **Fluid Simulation for Video Games**

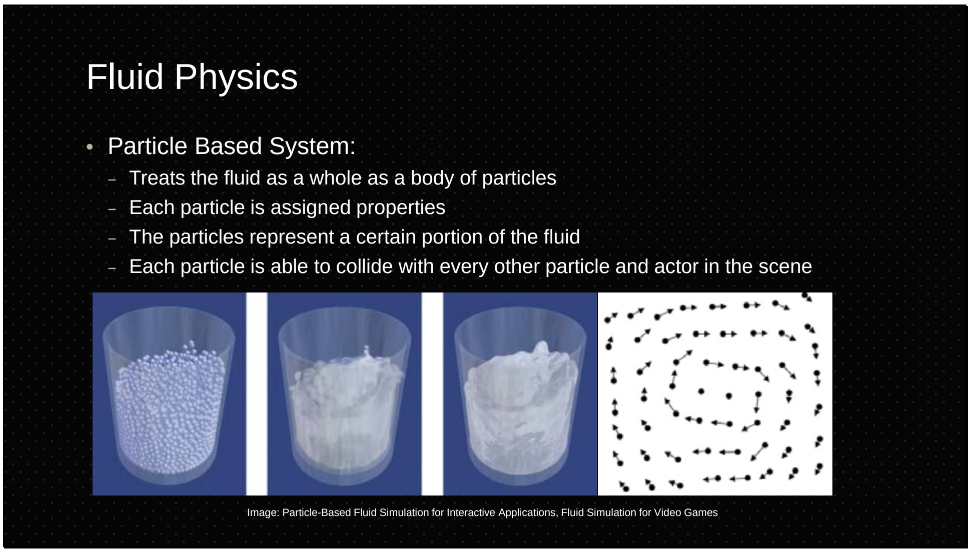
The Eulerian view of simulating the fluid treats the fluid as a field.

To each point in a region containing fluid, you can ascribe a set of properties such as velocity, density, temperature, and pressure. The positions of the points never move.

As the fluid is simulated, it is treated as a whole that has particular properties at set points that define the fluids bounds.

Fluids using this method use a 2 and a half dimensional height field representation. Removing interesting features of a full 3D simulation such as splashes and overturning waves get lost because the height field representation cannot capture them.

Slide 15



Fluid Physics

- Particle Based System:
  - Treats the fluid as a whole as a body of particles
  - Each particle is assigned properties
  - The particles represent a certain portion of the fluid
  - Each particle is able to collide with every other particle and actor in the scene

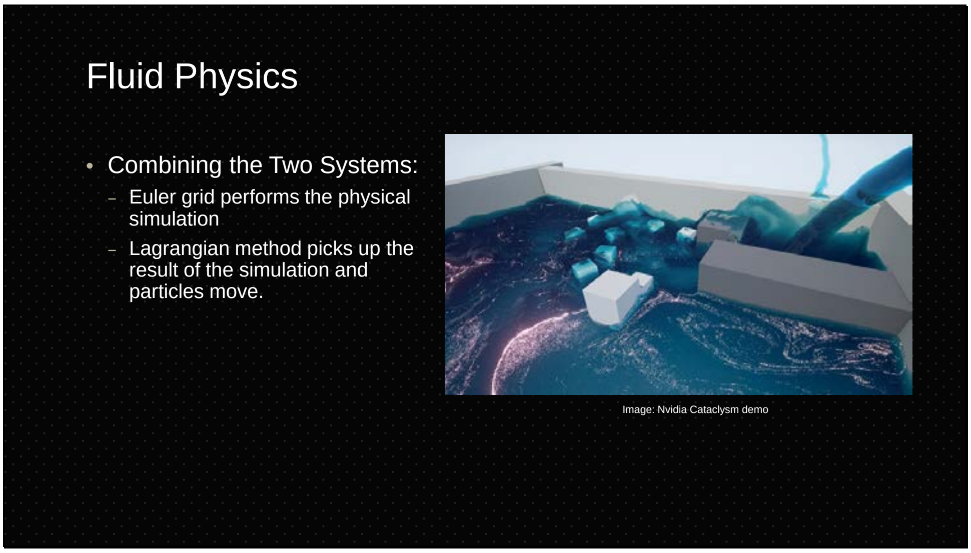
Image: Particle-Based Fluid Simulation for Interactive Applications, Fluid Simulation for Video Games

The Lagrangian view of simulating the fluid treats the fluid as a individual particles.

Each particle is assigned properties such as *position*, *velocity*, *density*, and *temperature*.

As the fluid is simulated, each particle represents a cluster of molecules that make up a fluid. Essentially you use statistics to use each particle in the fluid to represent a certain portion of the fluid. These particles are able to collide with every other particle and actor in the scene.

Slide 16



Fluid Physics

- Combining the Two Systems:
  - Euler grid performs the physical simulation
  - Lagrangian method picks up the result of the simulation and particles move.

Image: Nvidia Cataclysm demo

Generally to create an efficient fluid simulation in real time both methods are combined as a hybrid system as has been implemented in Cataclysm. Information for the fluid simulation is carried on particles, but the solution of the physical simulation of the liquid is carried out on a grid. Once the grid solve is complete, the particles gather back up the information they need from the grid move forward in time to the next frame.

Slide 17

Current Applications of Real Time Physics

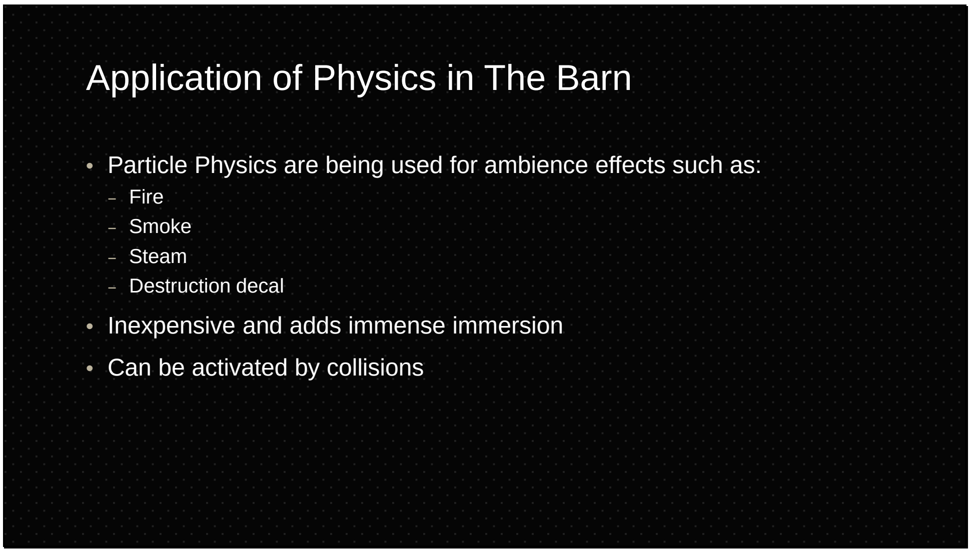
- Used in some way in most modern games

The least involved physics effects I am using in the Barn is particle effects. They are very inexpensive processing wise and add immense cinematic effect and player immersion.

Being used from fire, to ambience dust to destruction decal.

And they can be triggered on events

Slide 18



Application of Physics in The Barn

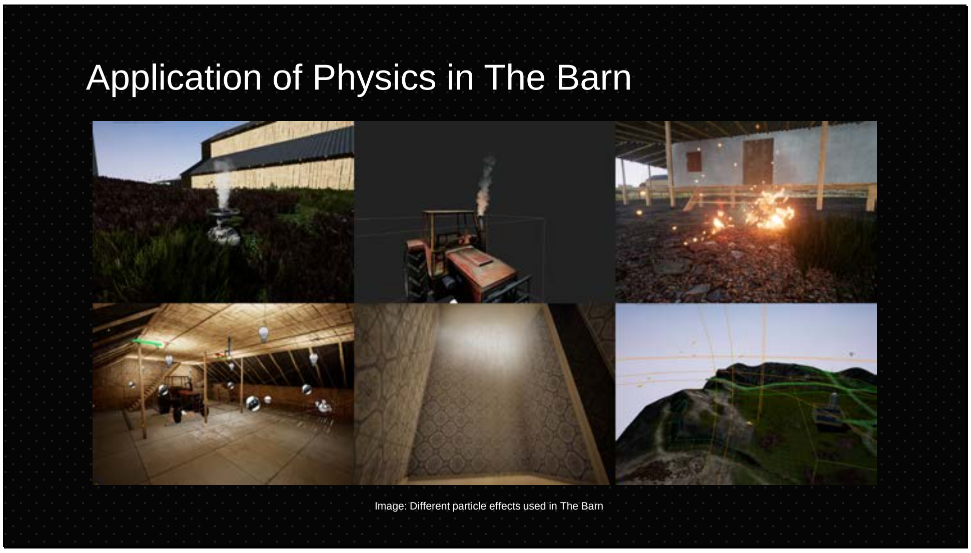
- Particle Physics are being used for ambience effects such as:
  - Fire
  - Smoke
  - Steam
  - Destruction decal
- Inexpensive and adds immense immersion
- Can be activated by collisions

The least involved physics effects I am using in the Barn is particle effects. They are very inexpensive processing wise and add immense cinematic effect and player immersion.

Being used from fire, to ambience dust to destruction decal.

And they can be triggered on events

Slide 19

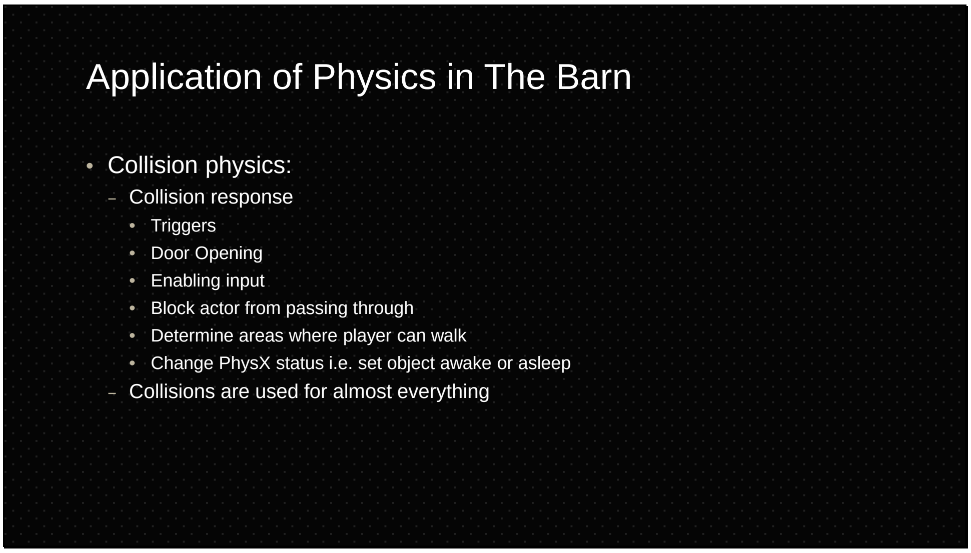


Application of Physics in The Barn

Image: Different particle effects used in The Barn

These are just a few examples of particle effects used in the Barn, the best example of how versatile they are is the bottom right where the particles are actually animated mesh birds that fly around a centre of the particle.

Slide 20



Application of Physics in The Barn

- Collision physics:
  - Collision response
    - Triggers
    - Door Opening
    - Enabling input
    - Block actor from passing through
    - Determine areas where player can walk
    - Change PhysX status i.e. set object awake or asleep
  - Collisions are used for almost everything

The most used simulation in The Barn is collision physics.

It is used to drive collision responses for triggers, opening doors, enabling player input, blocking actors from passing through each other, determines if the angle of the ground will allow the player to walk on it and changing physics states between awake and asleep for objects.

Basically collisions and collisions response are used for everything I am using in The Barn

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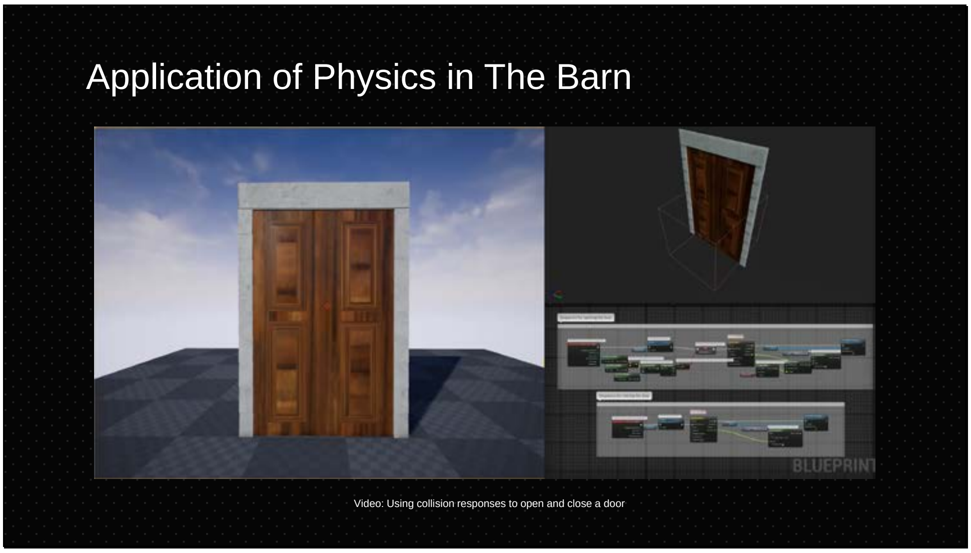

Application of Physics in The Barn

Video: Using collision responses to open and close a door

This is an example of using a collision overlap to trigger a door to open, collisions are the most basic physics used in The Barn.

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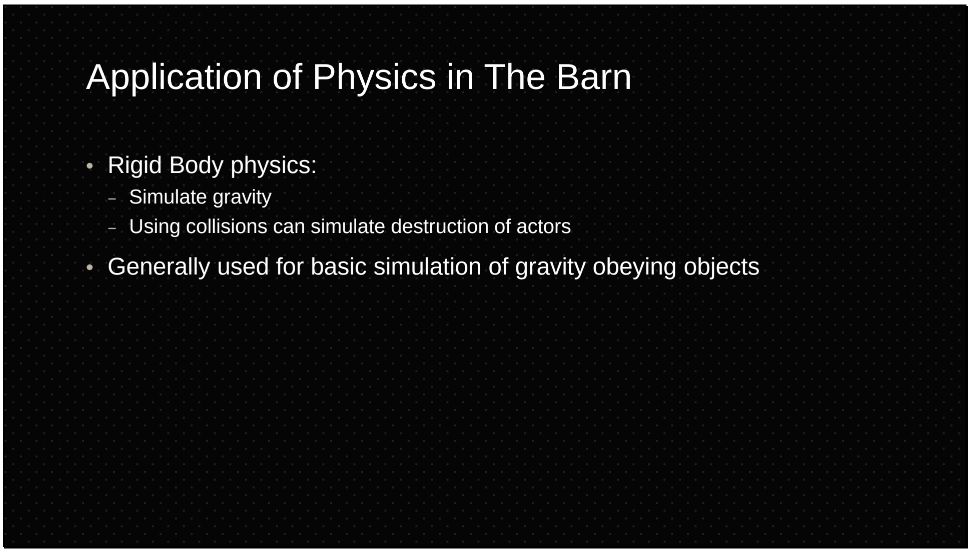

Application of Physics in The Barn

- Rigid Body physics:
  - Simulate gravity
  - Using collisions can simulate destruction of actors
- Generally used for basic simulation of gravity obeying objects

Rigid bodies are being used for everything the player will pick up and move around in the world. With the inventory, the player will be able to pick up a tape recorder and drop it on the flor if they wish and kick it around.

Rigid bodies are being used for destruction as well, I have destructible rigid bodies for walls that the player will be bale to break down to gain access to more areas inside the barn.

Basically everything that should be able to be moved in real life has rigid body simulations on it in the barn.

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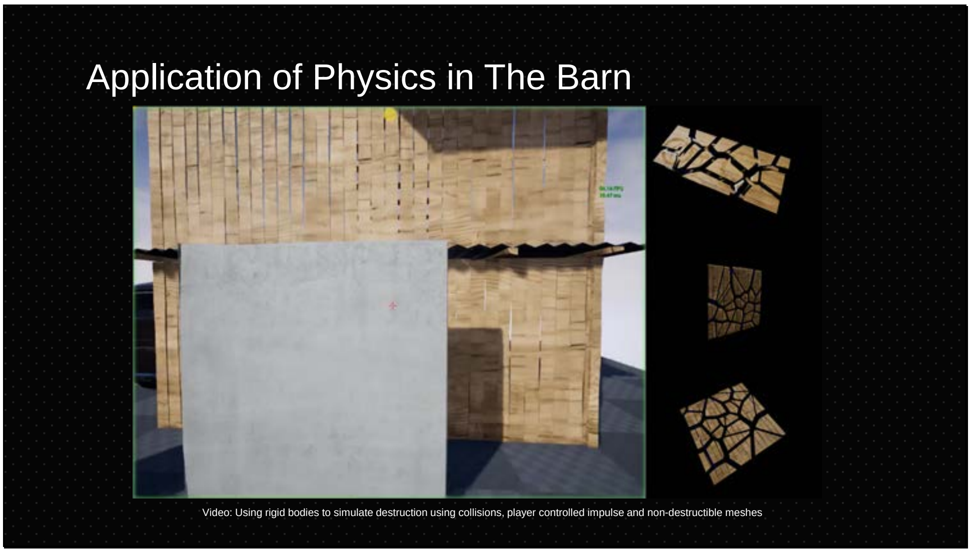

Application of Physics in The Barn

Video: Using rigid bodies to simulate destruction using collisions, player controlled impulse and non-destructible meshes

An example of using rigid bodies to create destructible objects using the player mass or using a controlled force emitter which is attached to the player.

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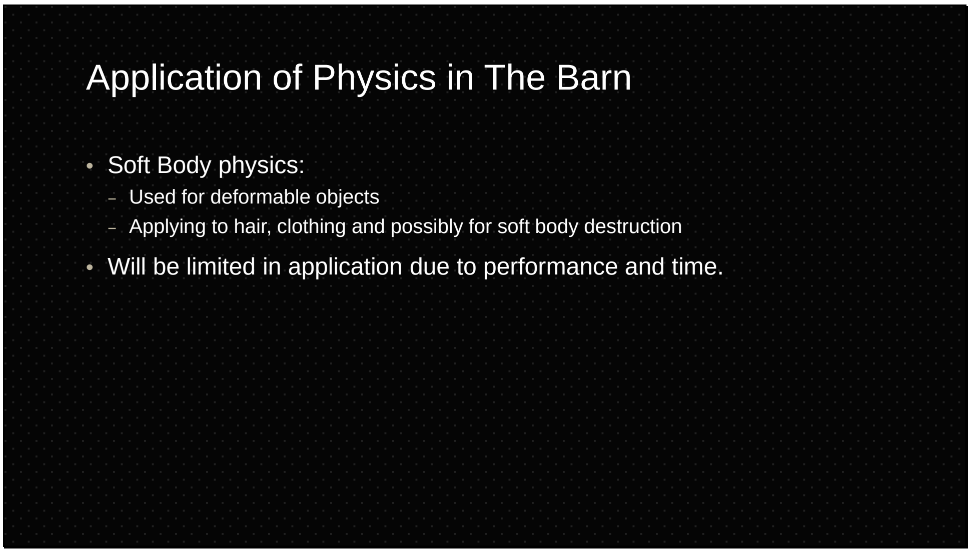

Application of Physics in The Barn

- Soft Body physics:
  - Used for deformable objects
  - Applying to hair, clothing and possibly for soft body destruction
- Will be limited in application due to performance and time.

The soft body physics used in the Barn are fairly limited due to performance and time constraints on getting the game ready for playing. The most used area where its being applied is to the grandmother characters hair and clothing in her skirt and possibly for soft body destruction of the car but we will see if I have the ability to do that.

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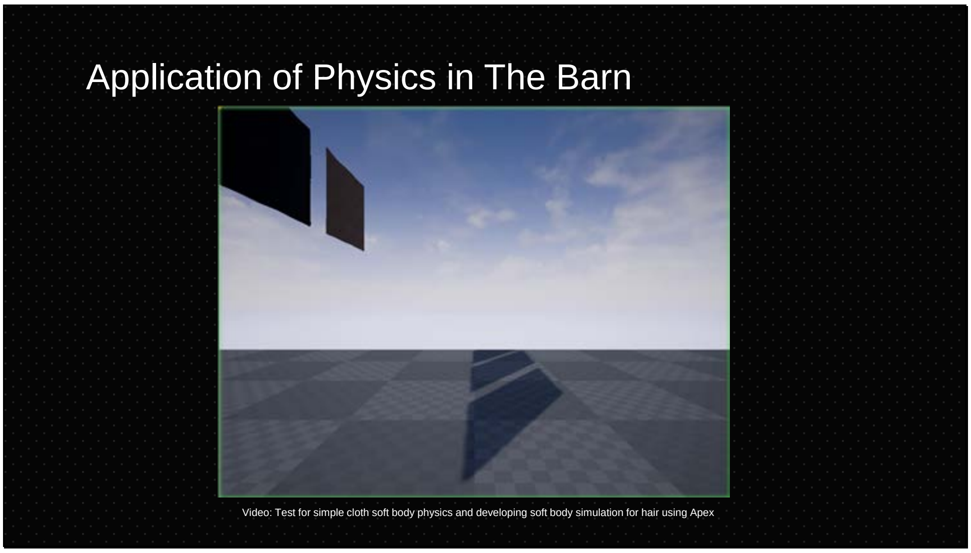

Application of Physics in The Barn

Video: Test for simple cloth soft body physics and developing soft body simulation for hair using Apex

This is an example of using soft body physics in Unreal engine and setting up the properties for soft body simulation on the Grandma characters hair.

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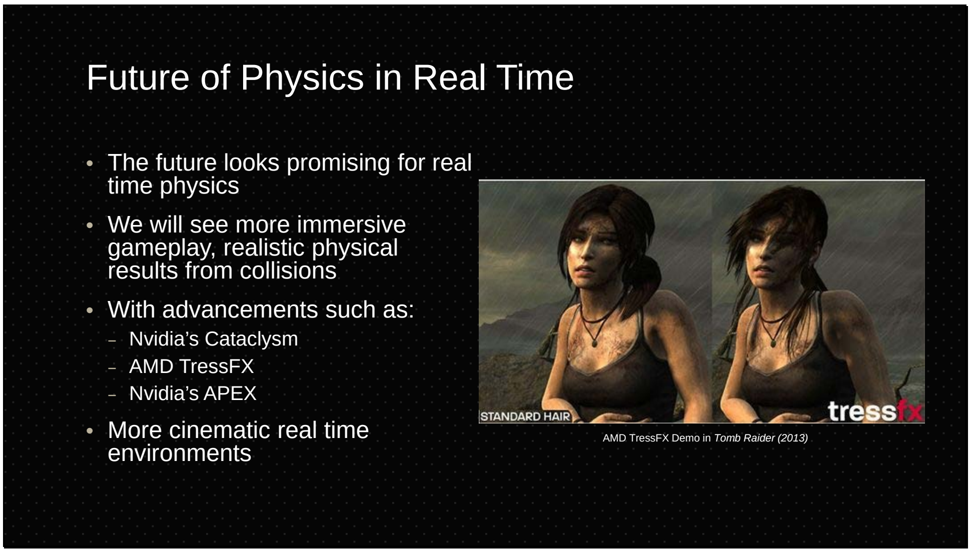

Future of Physics in Real Time

- The future looks promising for real time physics
- We will see more immersive gameplay, realistic physical results from collisions
- With advancements such as:
  - Nvidia's Cataclysm
  - AMD TressFX
  - Nvidia's APEX
- More cinematic real time environments

AMD TressFX Demo in *Tomb Raider (2013)*

The future of physics in real time platforms is very promising. We are seeing advancements like Cataclysm, TressFX and a lot of research put into creating fast and efficient real time simulations.

Better physics will result in more immersive and cinematic games that will emulate real life like only films have been able to do so far.

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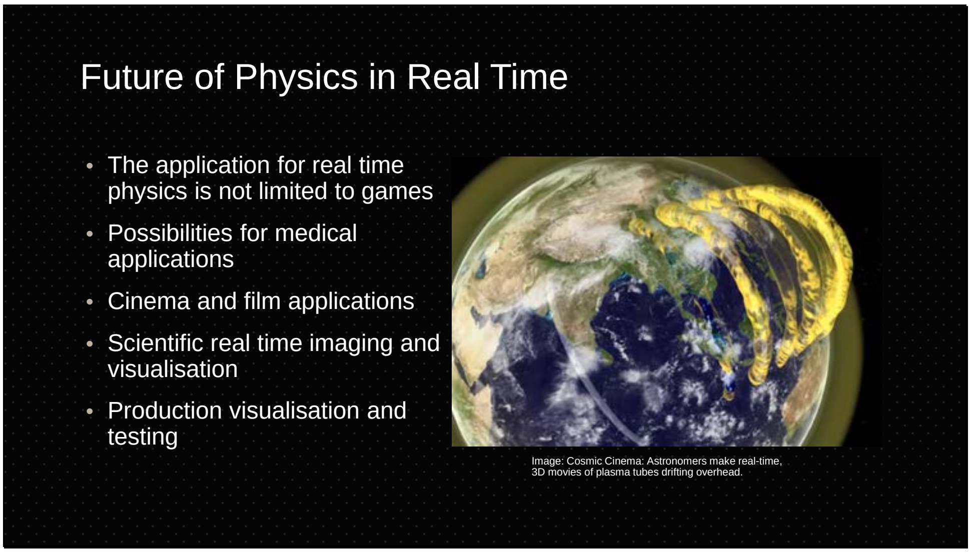

Future of Physics in Real Time

- The application for real time physics is not limited to games
- Possibilities for medical applications
- Cinema and film applications
- Scientific real time imaging and visualisation
- Production visualisation and testing

Image: Cosmic Cinema: Astronomers make real-time, 3D movies of plasma tubes drifting overhead.

Real time physics is limited to just games either, there are a multitude of new developments being made that are using real time physics. They include medical applications for simulating patient cardiovascular blood flow in patients, potential for films to be entirely created in real time platforms and scientific real time simulations of physical events.

There are also companies like Tesla who are currently hiring Unreal Engine artists to utilise the engine to visualise their cars using physics for soft body collision damage and driving characteristics.

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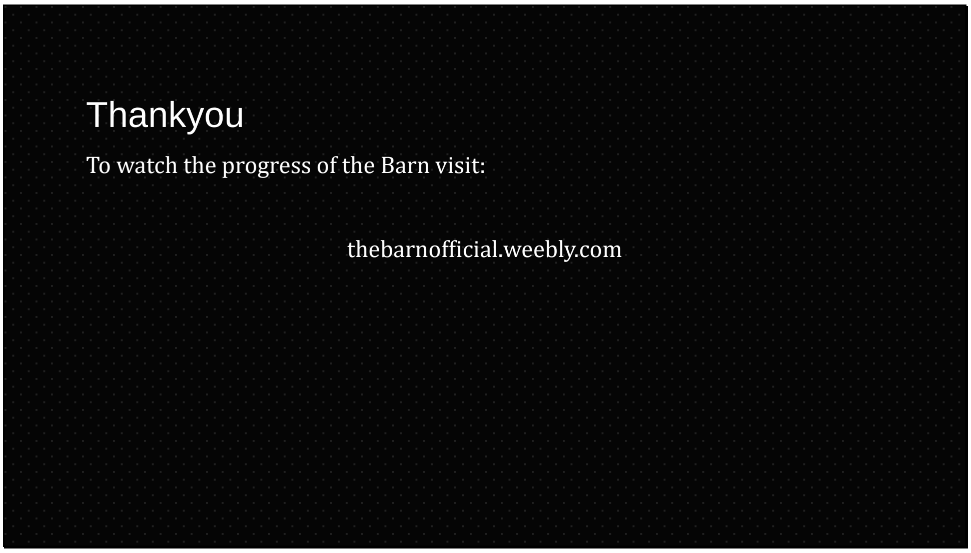

Thankyou

To watch the progress of the Barn visit:

thebarnofficial.weebly.com

Are there any questions?