OVERVIEW: PHYSICS

CS354P DR SARAH ABRAHAM

ASPECTS OF GAME PHYSICS

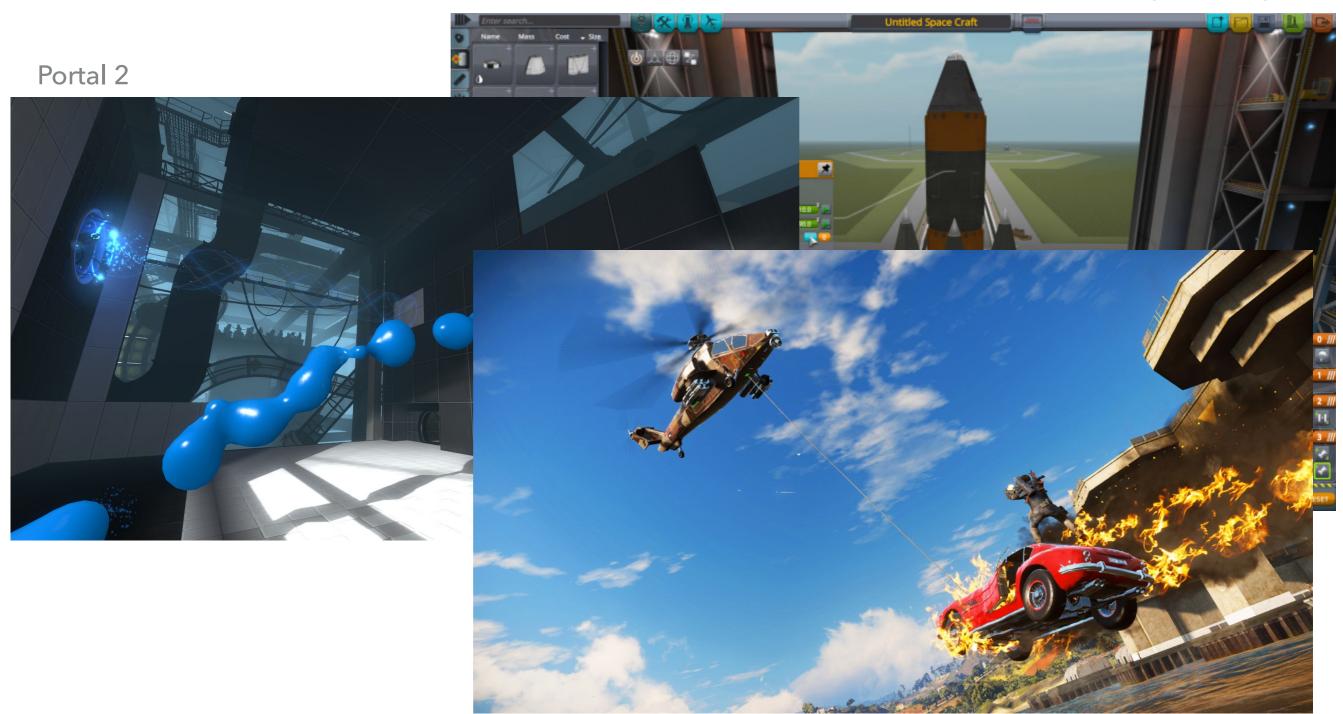
- Forces applied to objects
 - World systems and rules
 - Object interactions
- Physical representation of objects
 - Point masses
 - Rigid bodies
 - Soft bodies
- Collision detection of objects

FORCES APPLIED TO OBJECTS

- Many types of forces:
 - Gravity
 - Impulses
 - Drag
 - Restitution
 - Springs
 - etc...

FORCES IN ACTION

Kerbal Space Program



CLASSICAL MECHANICS

- Area of physics that explores motion of objects
 - Relationship between force, trajectories, acceleration, and mass
 - Newton's second law: F = ma
- Forces in game engines relate to object velocities and accelerations (mathematical vectors) and object masses
- What else do we need to know to calculate forces?

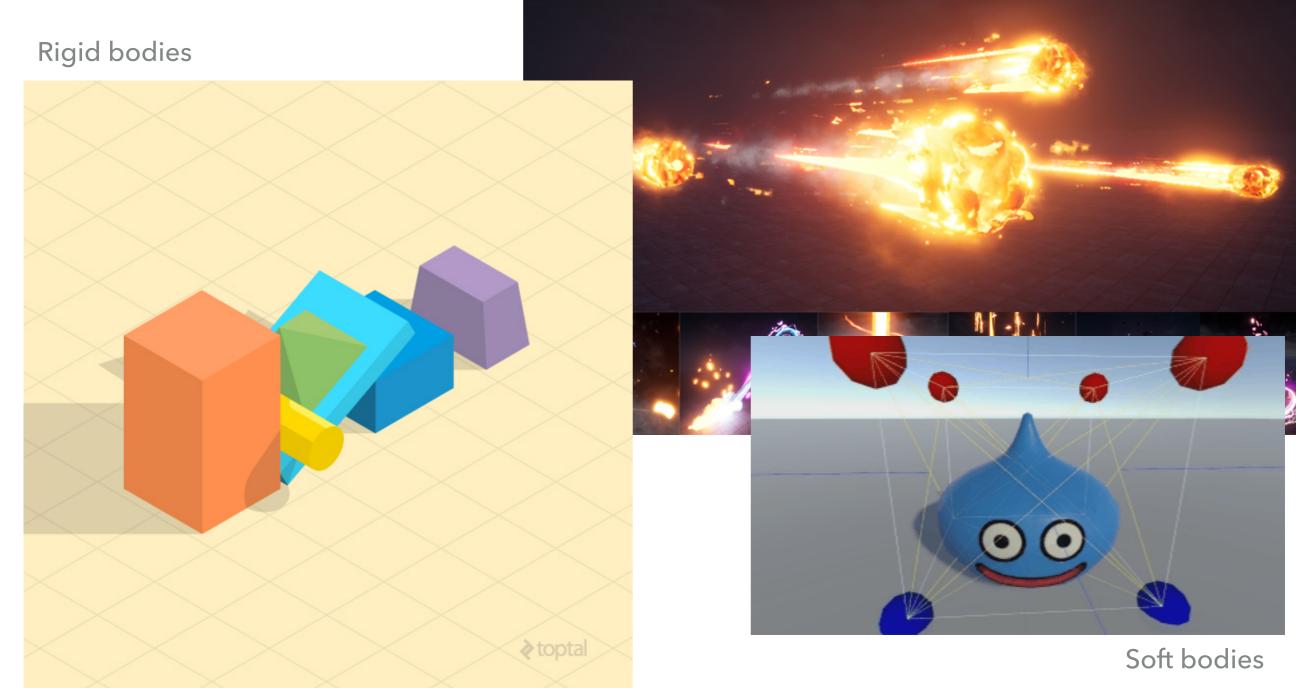
OBJECT REPRESENTATION

- Simplest representation of an object is a **point mass**
 - Position and mass with no volume (infinitesimally small)
 - Simplifies physical calculations
- Better representation is a rigid body
 - Object has volume but no deformation
 - More complex calculations to account for angular position and velocity
- Most accurate representation is a soft body
 - Object has volume and deformation
 - Much more complex calculations due to no fixed distance between objects
 - Can be pretty well approximated with a rigid body systems of springs

OBJECT REPRESENTATIONS

Point mass particle systems

https://realtimevfx.com/t/unreal-engine-effects-in-marketplace/10088



https://github.com/chrismarch/SoftBodySimulation

COLLISION DETECTION

- Detection of collisions is a separate concern from application of forces
 - e.g. Collisions can result in an event trigger rather than a physical interaction
 - e.g. Forces can be applied to objects that are not collidable
- Detecting collisions can be as expensive (or more expensive!) than applying forces
 - Why?

WHEN TO DETECT?

How do we know when two objects are colliding/about to collide/have collided?



WHEN TO DETECT?

- We detect collisions (and current forces) per time step
 - > May be **based** on frame rate but should not be tied directly to frame rate
- > Detect object collisions before they occur (a priori)
 - Will the two objects hit based on their current trajectories in the next time step?
- Detect object collisions after they occur (a posteriori)
 - Did the two objects hit between the previous time step and the current time step?
- Why can't we try to detect when a collision happens?

UE5 AND PHYSICS

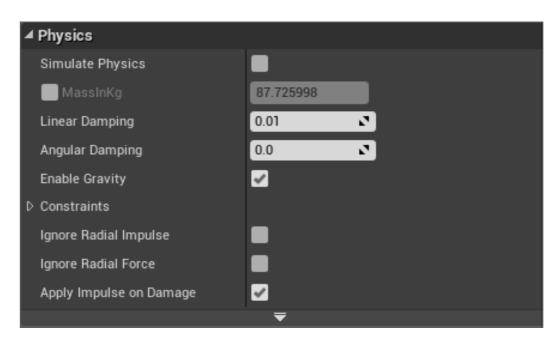
- Unreal uses Epic's Chaos physics engine
 - NVidia PhysX no longer supported
- Many advanced physical features supported in Unreal
 - Cloth
 - Fluid
 - Destruction
- We will mostly focus on the basics...

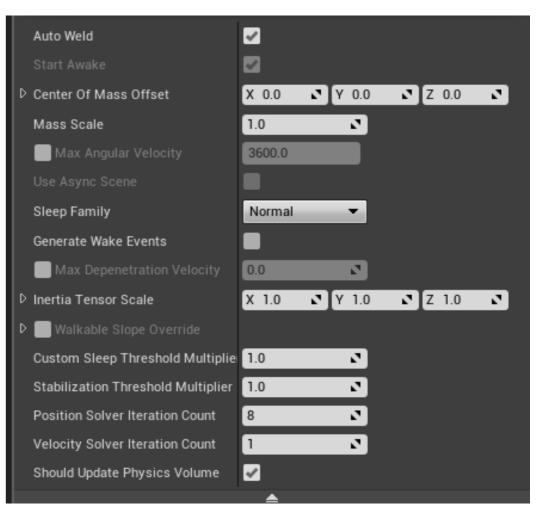
PHYSICS BODIES

- Simplified 3D meshes that Unreal uses to represent rigid bodies
 - Contains related physical and collision information
- Uses the FBodyInstance struct to store information

PHYSICS PROPERTIES

- Simulate Physics determines if body is simulated or kinematic (i.e controlled outside of simulation)
- Linear and angular damping are drag forces
- Constraints lock rotations to an axis
- And more...

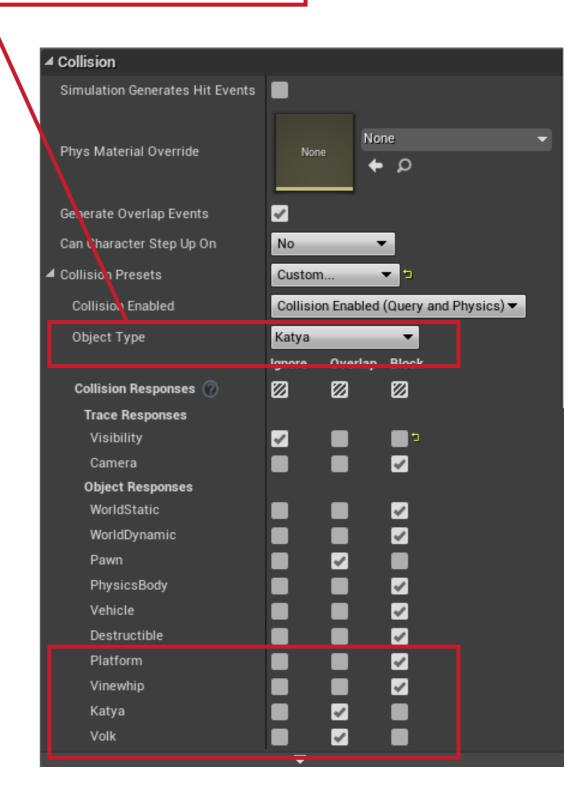




COLLISION PROPERTIES

- Can generate "Hit" and "Overlap" events to perform actions after a collision
- Type of collision responses based on object type, collision type, and other object type
 - Physics allows for physical simulation
 - Queries allow for spatial checks (overlaps, raycasts, sweeps)
- Can define additional Object/Trace
 Channels for collision response

Custom channels for custom functionality and handling



COLLISION SETTINGS

- Collision settings (like most engine settings) under Edit -> Project
 Settings
- Settings stored in the .ini files found in the Config folder
 - Can look through and edit this in plain text as well

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ngir	ne - Collision					
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PHYSICS SETTINGS

- Physics settings also under
 Edit -> Project Settings
- Determines
 parameterizations for the physics simulation in Chaos as well as memory usage/ accuracy

What's this?

✓ Constants						
Default Gravity Z	-980.0					
Default Terminal Velocity	4000.0					
Default Fluid Friction	0.3					
Simulate Scratch Memory Size	262144					
Ragdoll Aggregate Threshold	4					
	₹					
▲ Simulation	-					
Enable 2DPhysics						
Default Degrees Of Freedom	Full 3D					
Bounce Threshold Velocity	200.0					
Friction Combine Mode	Average 👻					
Restitution Combine Mode	Average 👻					
Max Angular Velocity	3600.0					
Max Depenetration Velocity	0.0					
Contact Offset Multiplier	0.02					
Min Contact Offset	2.0					
Max Contact Offset	8.0					
Simulate Skeletal Mesh on Dedicated Server						
Default Shape Complexity	Simple And Complex -					
Disable CCD						
Enable Enhanced Determinism						
	₹					
Optimization	-					
Suppress Face Remap Table						
Support UV From Hit Results						
Disable Active Actors						
▲ Framerate						
Max Physics Delta Time	0.033333					
Substepping						
Substepping Async						
Max Substep Delta Time	0.016667					
Max Substeps	6					

PHYSICS TIME STEP

- Physics is continuous but our simulations are not
- Must approximate physical interactions within a time step
 - Larger time steps are generally faster but less accurate
 - Fixed time steps are generally better for stability
- How does this relate to frame rate?

FRAME RATE AND SUB-STEPPING

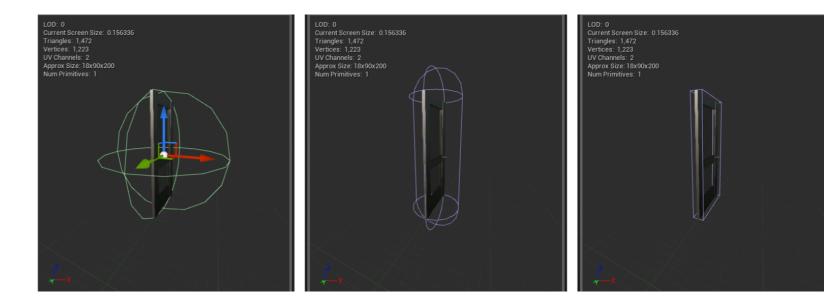
- We often want physics tied to frame rate to ensure responsiveness but frame rate is highly variable
 - Naively connecting time steps to frames may result in physics bugs/ inaccuracies
- Solution: sub-stepping divides a frame into smaller physics time steps which execute each frame
 - Extra time can roll over to the next frame
- Enabling sub-stepping incurs execution overhead but results in better accuracy
- Side note: collision callbacks are delayed until the final sub step is finished for threading efficiency
 - Thus you can have multiple callbacks for an object executed within a single frame in FIFO order

COLLISION VOLUMES

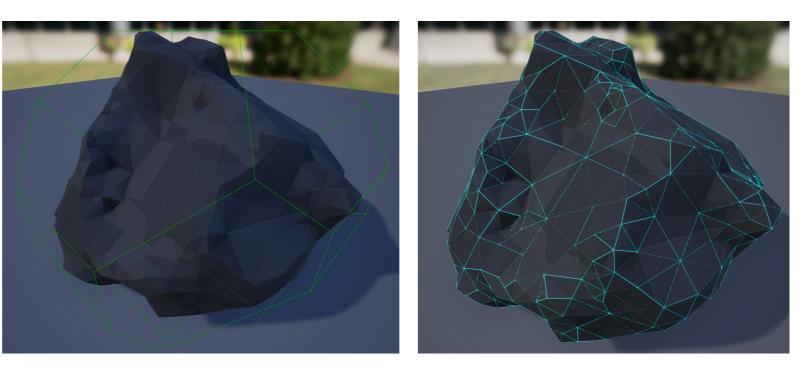
- Collision checking is based on the mesh faces of an object
 - Must consider how the interactions per-face of an object's mesh will impact the collision
 - Similar problems/solutions in graphics: spatial data structures, fast intersection tests etc
- High level idea: simpler collision volumes means faster collision checks

UNREAL COLLISION VOLUMES

 Can compose collision volumes out of simple shapes: boxes, spheres, capsules



- Or generate collision
 volumes from a mesh
 (simple vs complex)
- How should you decide?



STATIC VS SKELETAL MESHES

- Static meshes are the standard meshes used to create world geometry
 - > Set of polygons that can be cached in video memory for efficient rendering
 - Can apply affine transformations (scale, rotate, translate) but not other vertex manipulations
- Skeletal meshes are meshes that have hierarchical controls used to create characters and other animating objects
 - Set of polygons manipulated via a skeleton
 - Vertices move relative to they underlying skeleton based on skinning algorithm
 - Can convert skeletal meshes to static meshes to save poses but will not generally work for dynamic scenes

PHYSICS CONSTRAINTS AND DAMPING

- Constraints can be used to connect actors in a physically-based way
- Constraints are types of joints (ball-and-socket, hinge, etc) but can also be customized
- > Physics Constraints can be actors or components
 - Actors placed into a scene
 - Components placed into an actor
- Can apply a wide range of parameters to emulate different physical behaviors
- Can test using "Play" in editor or "Simulate"
- Read here for more tutorial information: <u>https://docs.unrealengine.com/en-US/Engine/Physics/Constraints/index.html</u>

PHYSICS CONSTRAINTS IN C++

- All Blueprint constraints can be done in C++
 - I'd recommend quick prototyping in Blueprint, building the foundation in C++, then building the in-game instance in Blueprint based on the C++
 - In this may seem round-about, but it will generally result in pretty fast development cycle, good looking code, and a designer-friendly final product
- Must create and attach static mesh components then create an FConstraintInstance to set properties in code
- Any Blueprint class created from this C++ class will have values set in the C++ constructor
 - Remember to make the UPROPERTY BlueprintReadWrite if you want values accessible within the Blueprint

PHYSICS CONSTRAINTS C++ EXAMPLE

stable component is fixed; bounce component moves relative to it



PHYSICAL MATERIALS

- Unreal uses physical materials to define an object's interactions with the world
 - Can adjust parameterization to be applied to any object using that material
 - Can be use in conjunction with regular materials (i.e. the shaders and lighting models used on objects for rendering)

CLOTH SIMULATION

- Unreal uses Chaos Cloth solver to create cloth effects
 - Uses a particle system with constraints to create clothlike movements and collision responses
- Unreal allows artists to import cloth asset then paint "clothiness" onto mesh
 - Determines how much the individual parts react like cloth

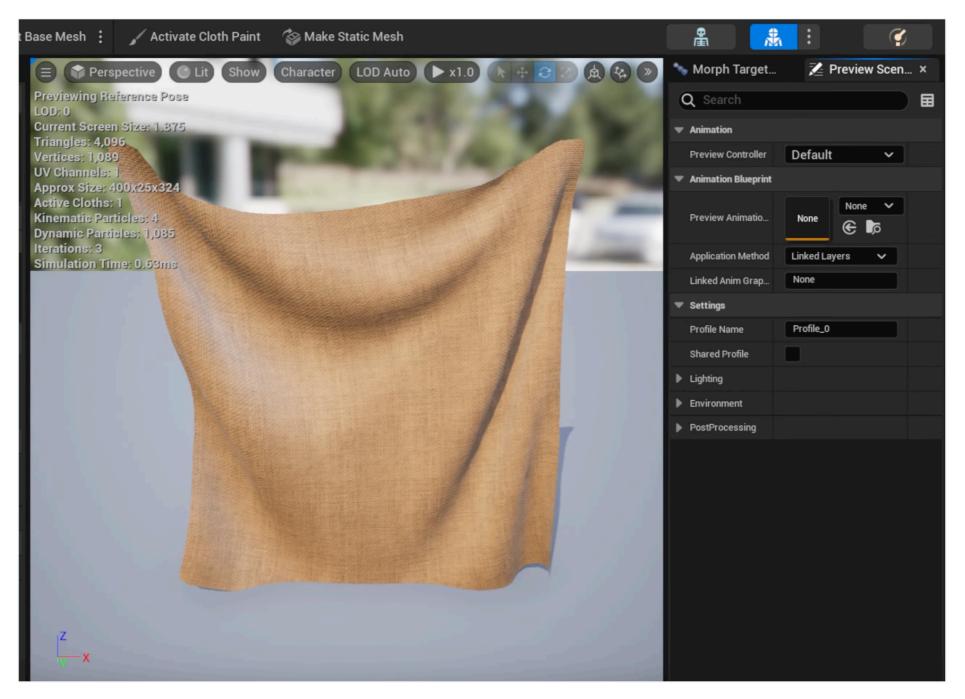
DESTRUCTIBLE ACTORS

- Unreal uses Chaos Destruction to create destructible meshes
 - Allows static meshes to be broken into dynamic pieces in a parametrizable way
 - Works in real time
- Can be integrated with Niagra particle system and Audio Mixer to incorporate VFX and SFX

CS354P

CHAOS CLOTH DEMO

https://youtu.be/un6ZNdcxQlk?si=fEHwhQ0WitotpqD4&t=552



CHAOS DESTRUCTION DEMO

https://www.youtube.com/watch?v=XaPECMAKbSI

