CS354P

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OVERVIEW: PHYSICS

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

Portal 2

Just Cause 3

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

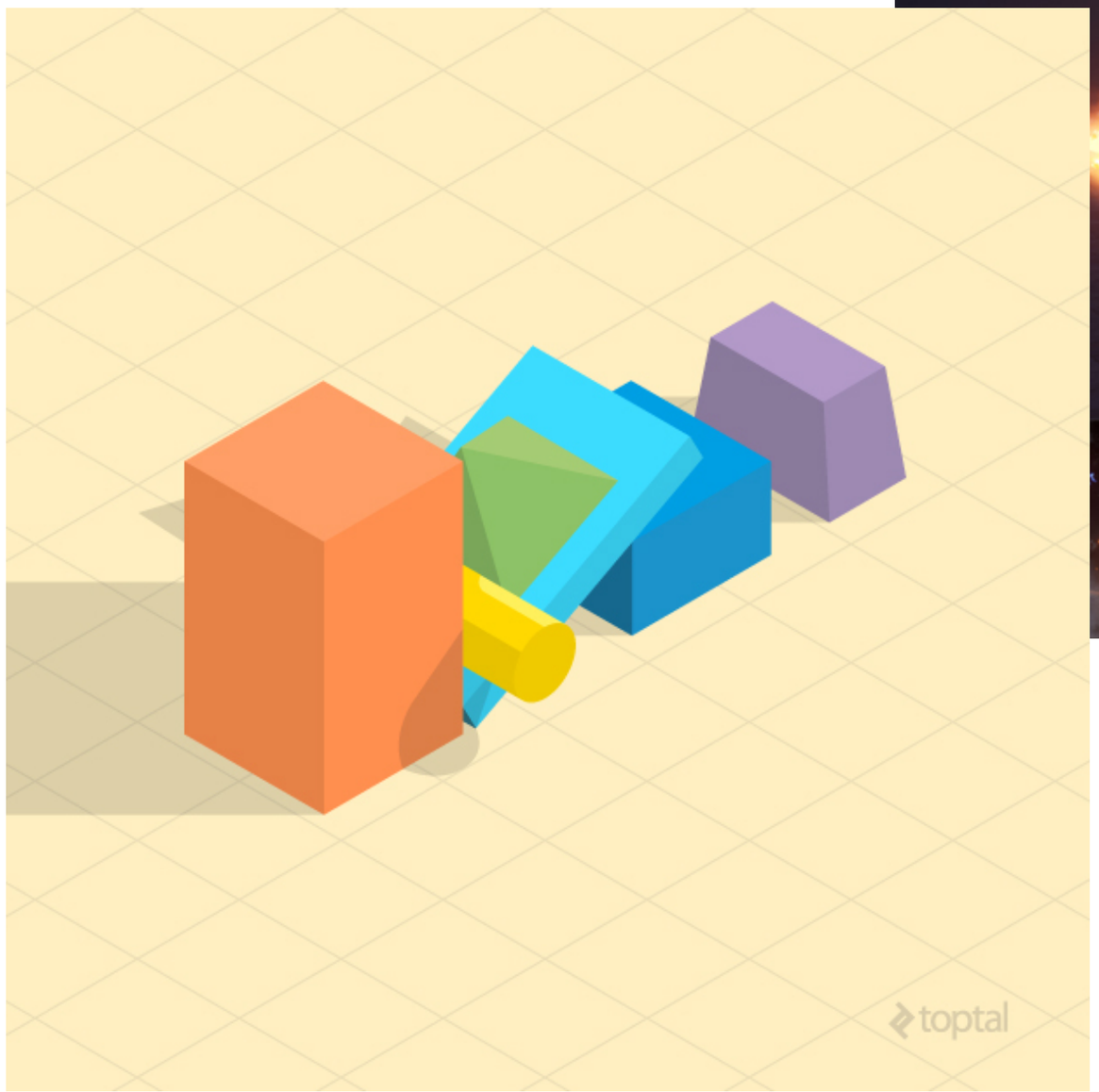
- Simplest representation of an object is a **point mass**
  - Position and mass with no volume (infinitesimally small)
  - Simplifies physical calculations
- Better representation is a **rigid body**
  - Object has volume but no deformation
  - More complex calculations to account for angular position 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

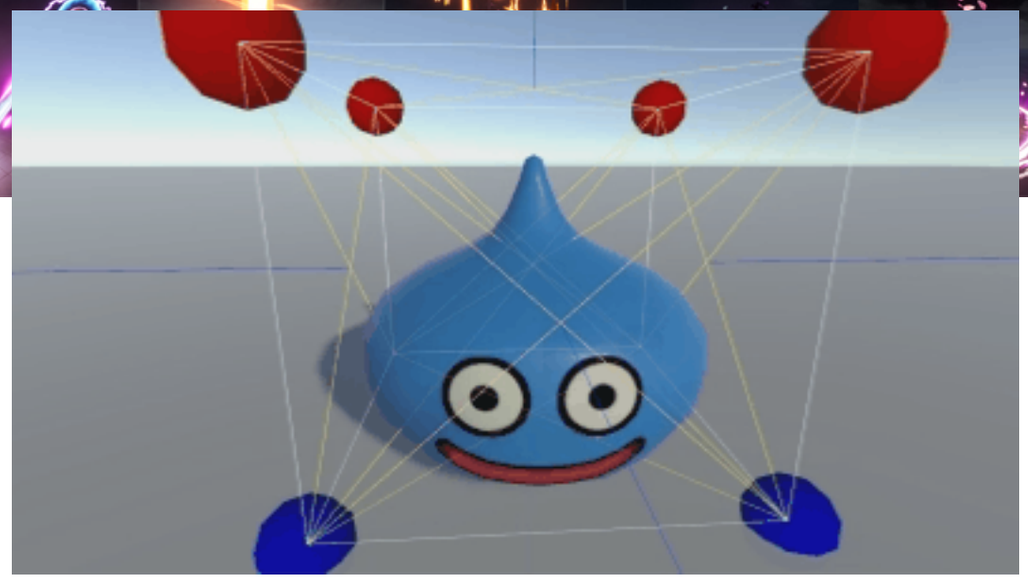
OBJECT REPRESENTATIONS

Point mass particle systems

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

Rigid bodies





Soft bodies

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

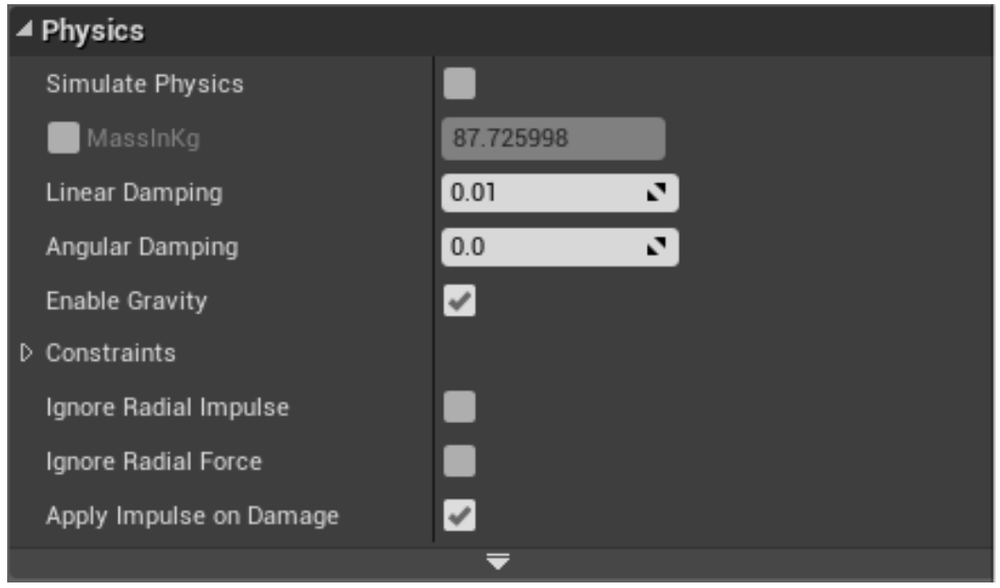
- Unreal uses Epic's Chaos physics engine
  - NVidia PhysX no longer supported
- Many advanced physical features supported in Unreal
  - Cloth
  - Fluid
  - Destruction
- We will mostly focus on the basics...

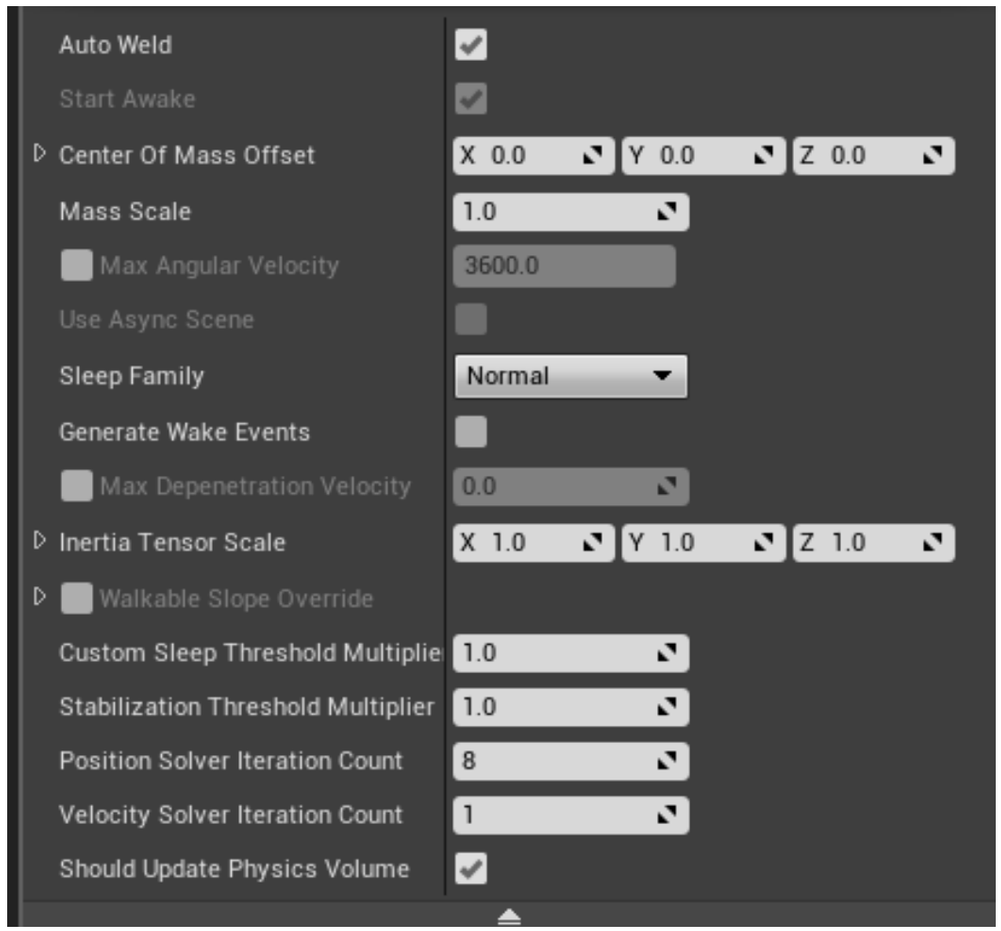
PHYSICS BODIES

- 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...

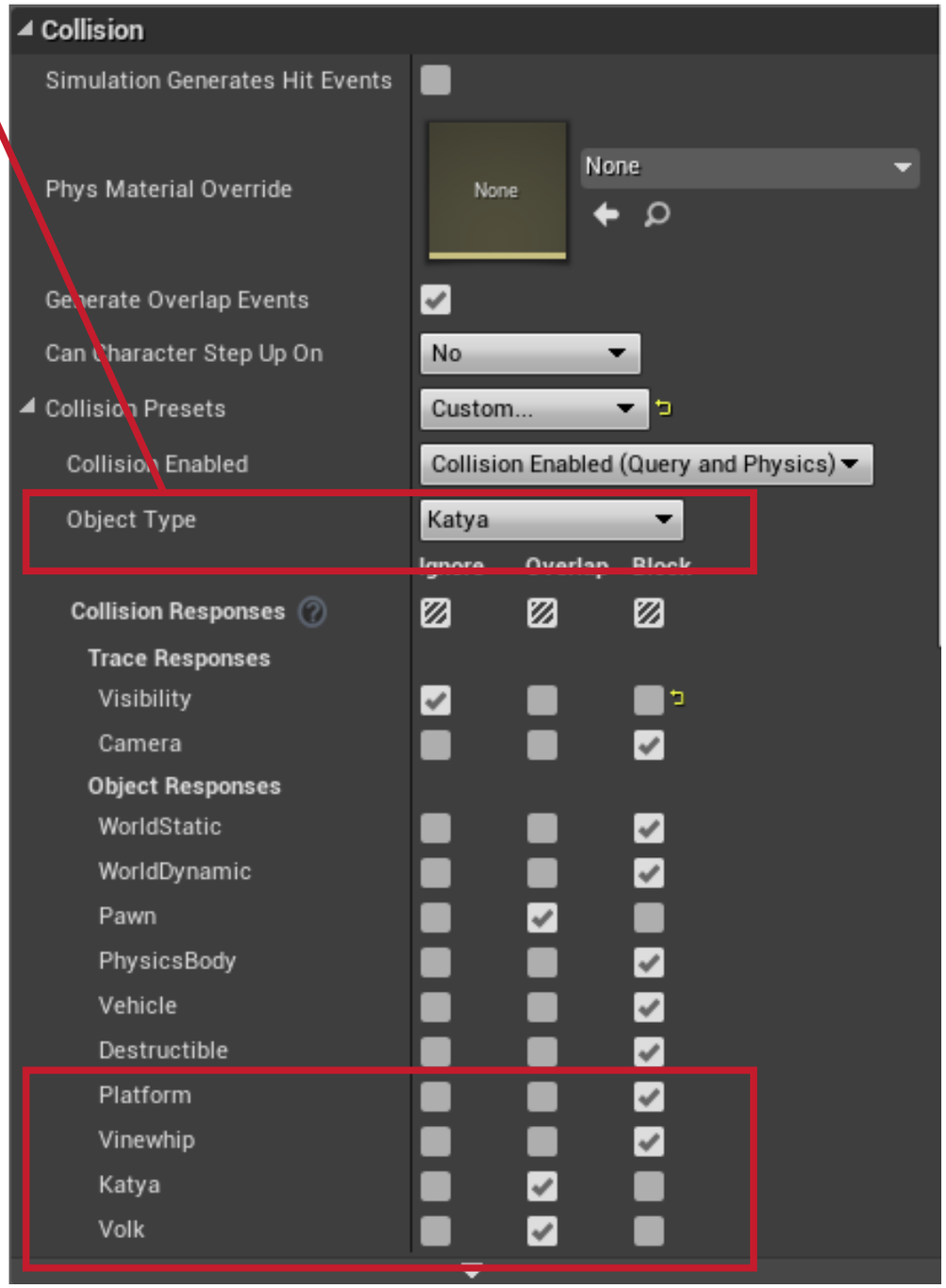




COLLISION PROPERTIES

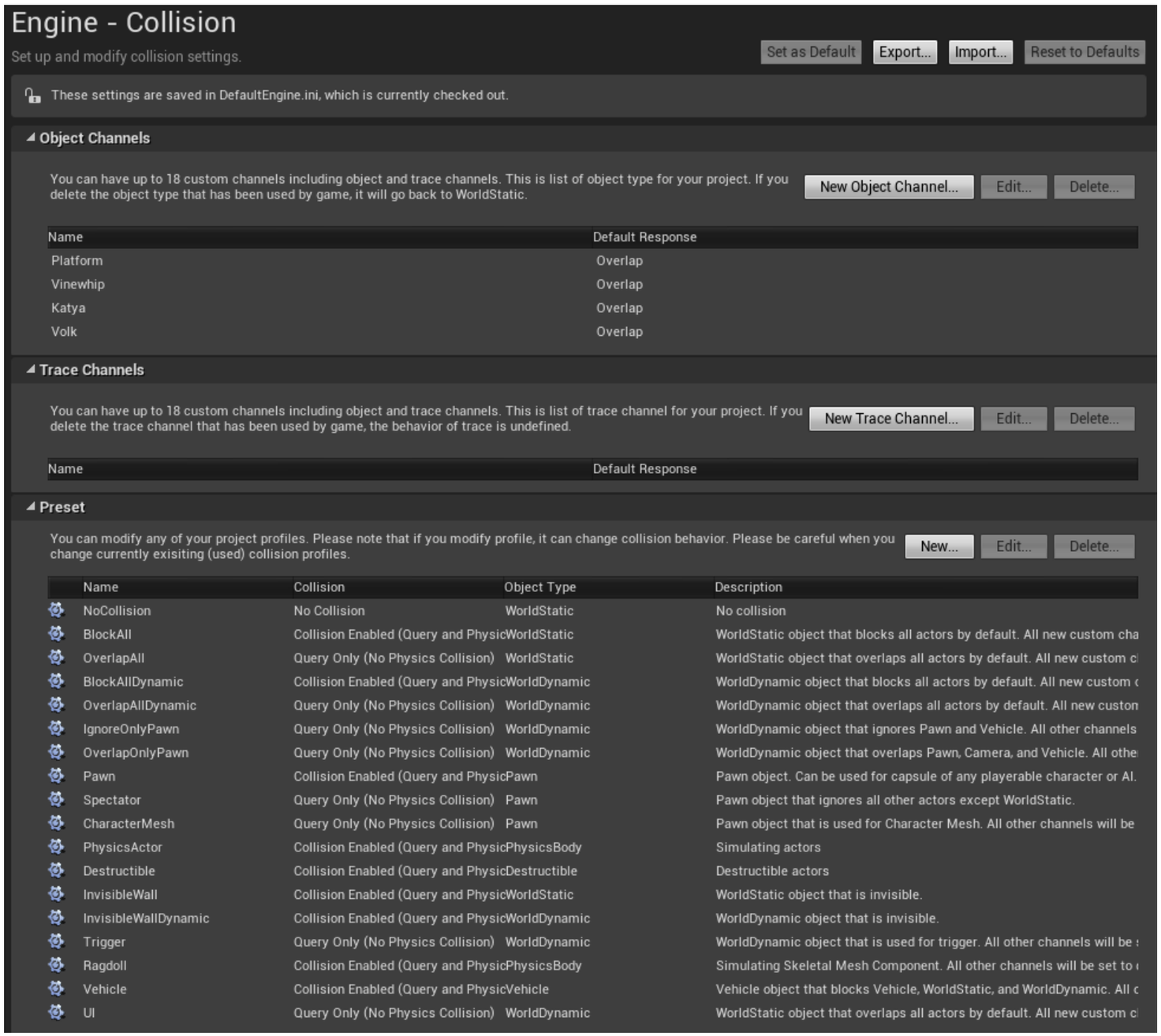
- Can generate “Hit” and “Overlap” events to perform actions after a collision
- Type of collision responses based on object type, collision type, and other object type
  - Physics allows for physical simulation
  - Queries allow for spatial checks (overlaps, raycasts, sweeps)
- Can define additional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

Custom channels for custom functionality and handling



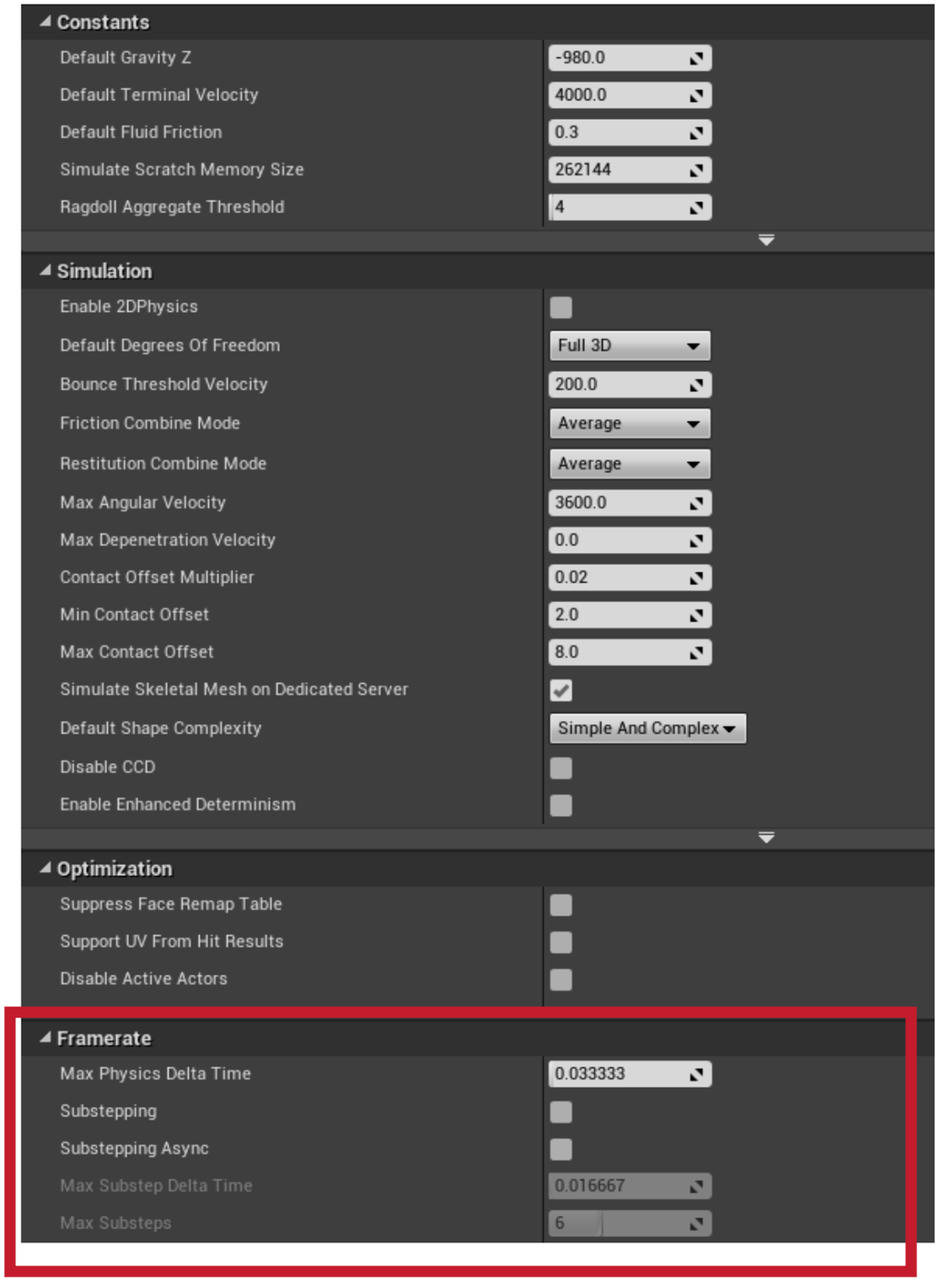
COLLISION SETTINGS

- 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



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?

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

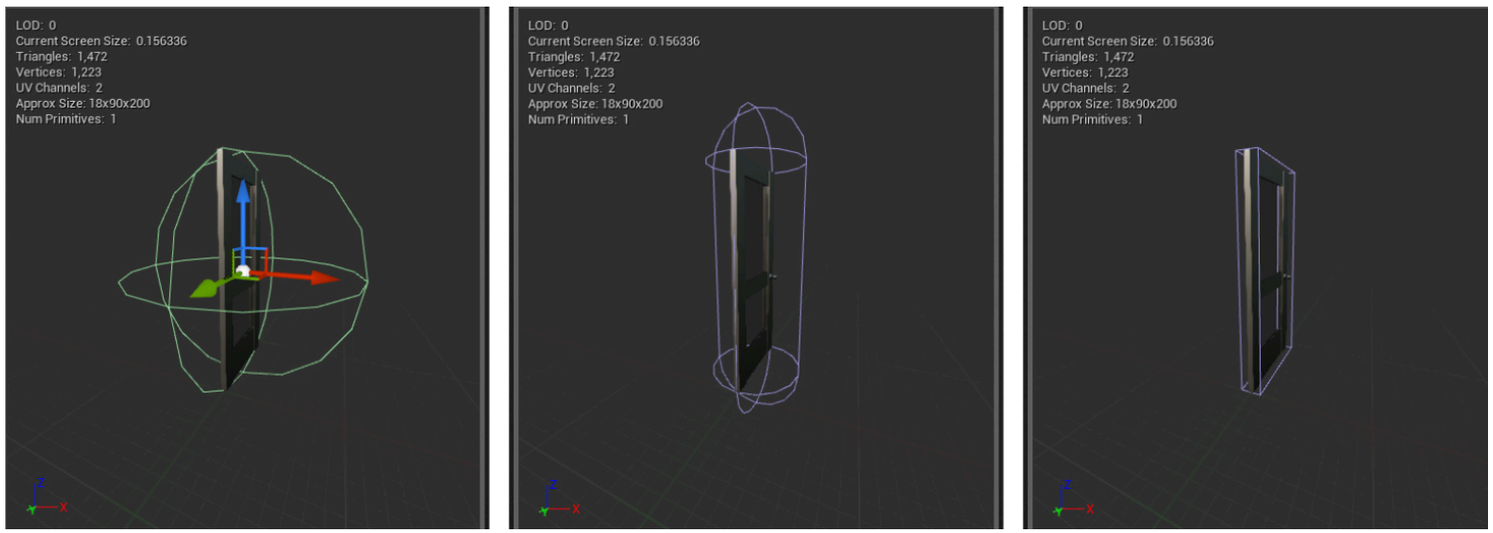
- We often want physics tied to frame rate to ensure responsiveness but **frame rate is highly variable**
  - Naively connecting time steps to frames may result in physics bugs/ inaccuracies
- Solution: sub-stepping divides a frame into smaller physics time steps which execute each frame
  - Extra time 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

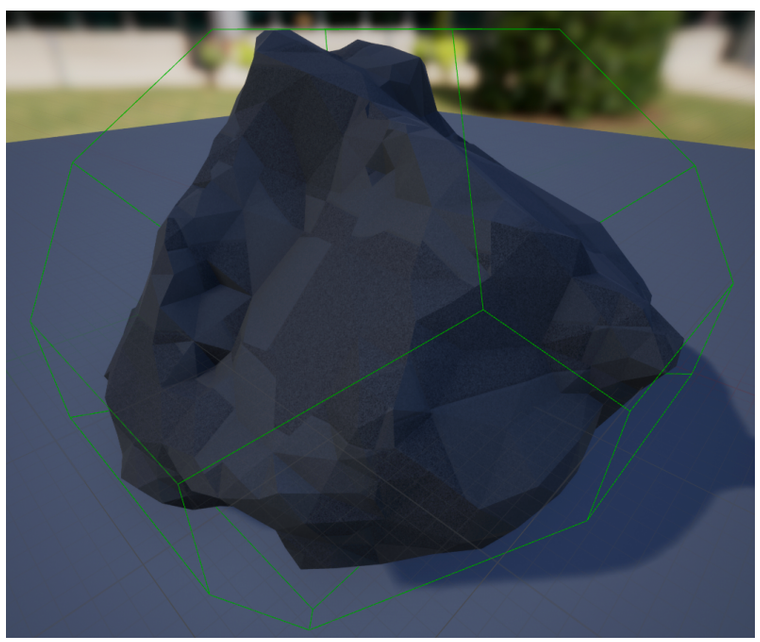
- Collision checking is based on the mesh faces of an object
  - Must consider how the interactions per-face of an object's mesh will impact the collision
    - Similar problems/solutions in graphics: spatial data structures, fast intersection tests etc
- High level idea: simpler collision volumes means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

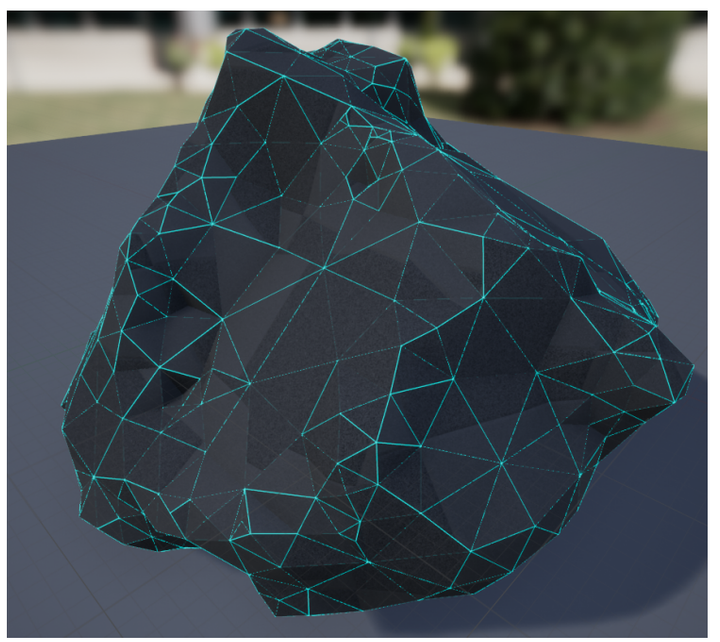
UNREAL COLLISION VOLUMES

- 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: https://docs.unrealengine.com/en-US/Engine/Physics/Constraints/index.html

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++
  - ...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

```
RootComponent = CreateDefaultSubobject<USceneComponent>(TEXT("RootComponent"));
stableComponent = CreateDefaultSubobject<UStaticMeshComponent>(TEXT("stableComponent"));
bounceComponent = CreateDefaultSubobject<UStaticMeshComponent>(TEXT("bounceComponent"));
stableComponent->AttachToComponent(RootComponent, FAttachmentTra
bounceComponent->AttachToComponent(RootComponent, FAttachmentTra
```

Set properties of constraint interactions (in this case, a bouncy platform)

```
FConstraintInstance platformConstraintInstance;
FConstraintProfileProperties platformConstraintProperties =
platformConstraintInstance.ProfileInstance;
platformConstraintInstance.SetLinearXMotion(ELinearConstraintMotion::LCM_Limited);
platformConstraintInstance.SetLinearYMotion(ELinearConstraintMotion::LCM_Locked);
platformConstraintInstance.SetLinearZMotion(ELinearConstraintMotion::LCM_Limited);
platformConstraintInstance.ProfileInstance.LinearLimit.Limit = 5.0;
platformConstraintInstance.ProfileInstance.LinearLimit.bSoftConstraint = true;
platformConstraintInstance.ProfileInstance.LinearLimit.Stiffness = 3000.0;
platformConstraintInstance.ProfileInstance.LinearLimit.Restitution = 1.0;
platformConstraintInstance.ProfileInstance.LinearLimit.ContactDistance = 1.0;
platformConstraintInstance.SetAngularSwing1Limit(EAngularConstraintMotion::ACM_Locked, 0);
platformConstraintInstance.SetAngularSwing2Limit(EAngularConstraintM
platformConstraintInstance.SetAngularTwistLimit(EAngularConstraintMo
platformConstraintInstance.ProfileInstance.ConeLimit.Stiffness = 100
platformConstraintInstance.ProfileInstance.ConeLimit.Restitution = 1.0;
```

constraint component connects the two “physical” pieces

```
constraintComponent =
CreateDefaultSubobject<UPhysicsConstraintComponent>(TEXT("platformConstraintComponent"));
constraintComponent->AttachToComponent(stableComponent,
FAttachmentTransformRules::KeepRelativeTransform);
constraintComponent->ConstraintInstance = platformConstraintInstance;
constraintComponent->SetConstrainedComponents(stableComponent, "Stable Component", bounceComponent,
"Bounce Component");
```

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

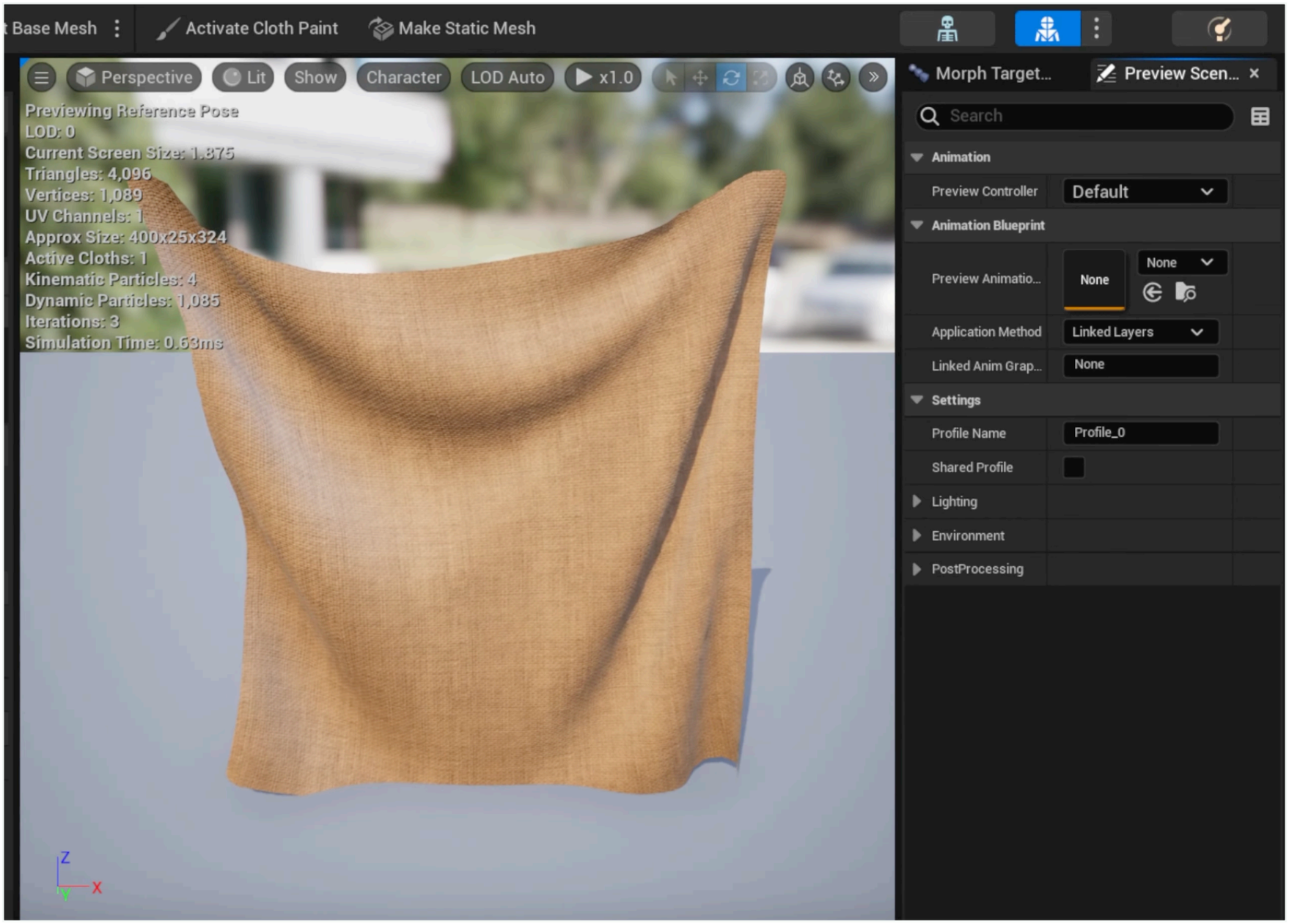
- Unreal uses Chaos Cloth solver to create cloth effects
  - Uses a particle system with constraints to create cloth-like movements and collision responses
- Unreal allows artists to import cloth asset then paint “clothiness” onto mesh
  - Determines how much the individual parts react like cloth

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

CHAOS CLOTH DEMO

- https://youtu.be/un6ZNdcxQIk?si=fEHwhQ0WitotpqD4&t=552



CHAOS DESTRUCTION DEMO

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