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asia pacific

Streaming & Serialisation For Unreal Open Worlds

Who am I?

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ANIMALLOGIC

Pipeline Engineer

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Indie Developer

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- Very little documentation on its features
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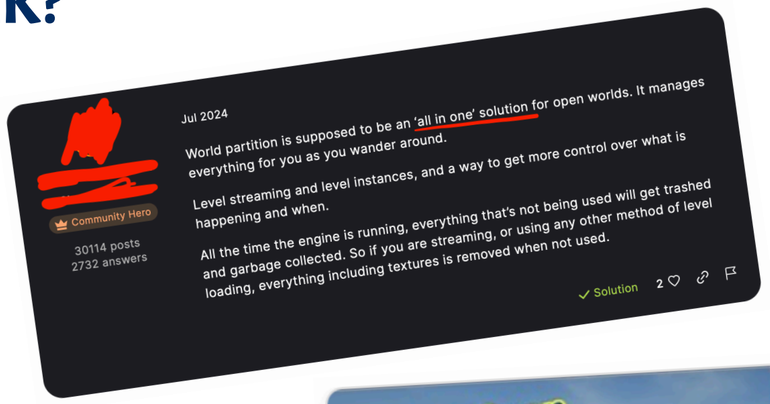
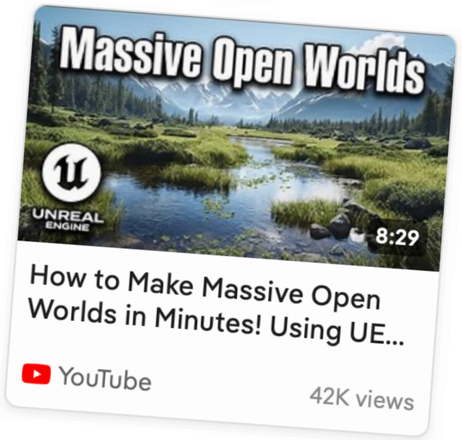
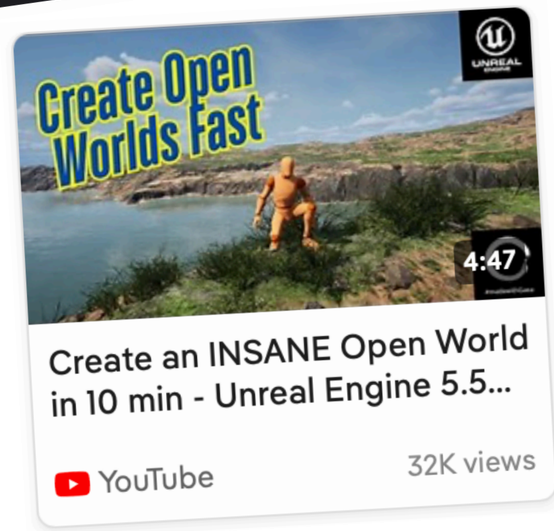
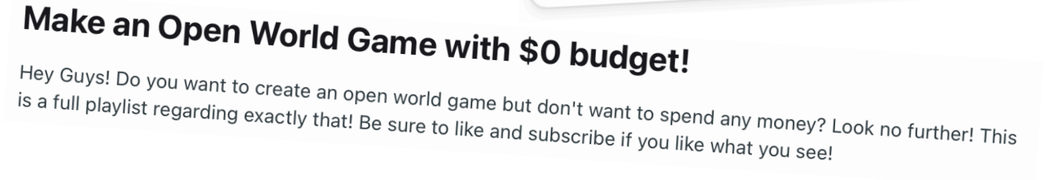
- NOT an "all in one" solution
- *People were wrong on the internet*









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- **NOT** a tutorial on "how to get started"
- **NOT** a step-by-step guide with code-snippets
- **NOT** a talk about asset streaming or to-disk serialisation
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"Why isn't my quest location showing up?"

"Why isn't the navmesh generating in builds?"

Don't worry, there will be a link to the slides provided!

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What to expect over the next 50 minutes

What are Unreal's World Partition systems?

Streaming systems for game state management

Serialisation systems for game state persistence

Wrap-up, summary and Q&A

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What are Unreal's World Partition systems?

- OFPA
- HLODs
- Grids
- Level Instances
- Packed Level Actors
- Smart Objects
- Data Layers

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Wrap-up, summary and Q&A

- Concluding Thoughts
- Other people talk for a bit

What Are Unreal's World Partition Systems?

One File Per-Actor (OFPA)

- World Partition's multi-user editing solution
- Enabled by default for World Partition levels
- Inverts the relationship between maps and actors
- Maps typically contain:
  - Settings
  - Metadata
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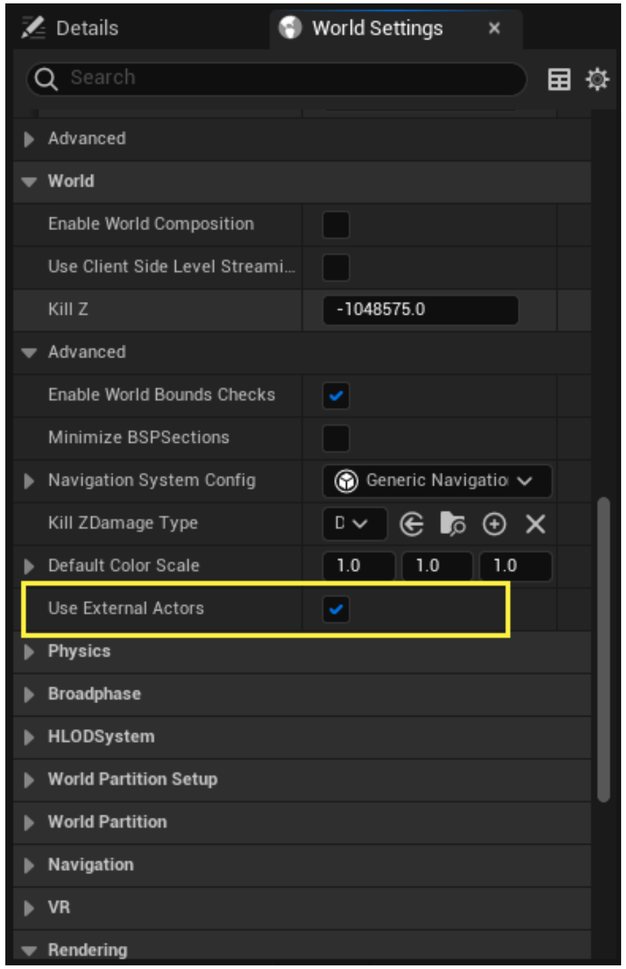

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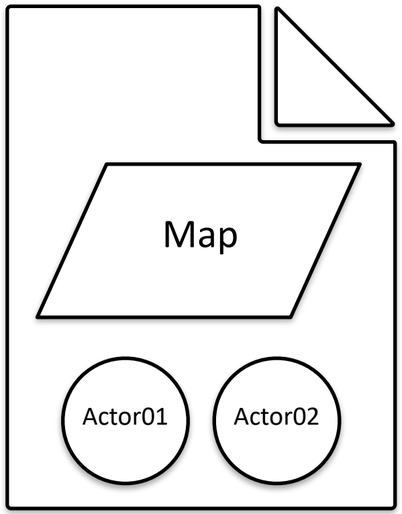

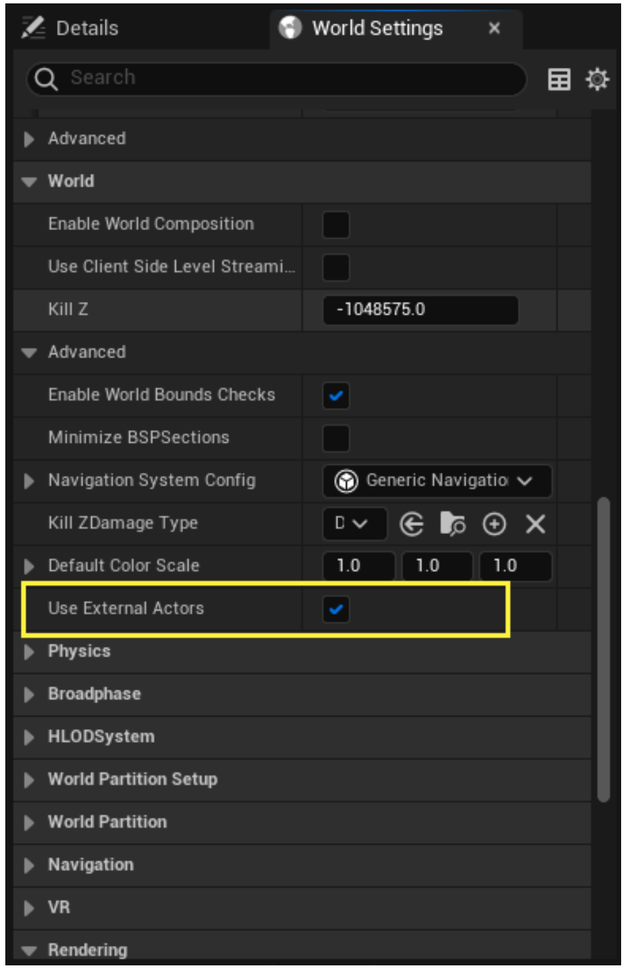

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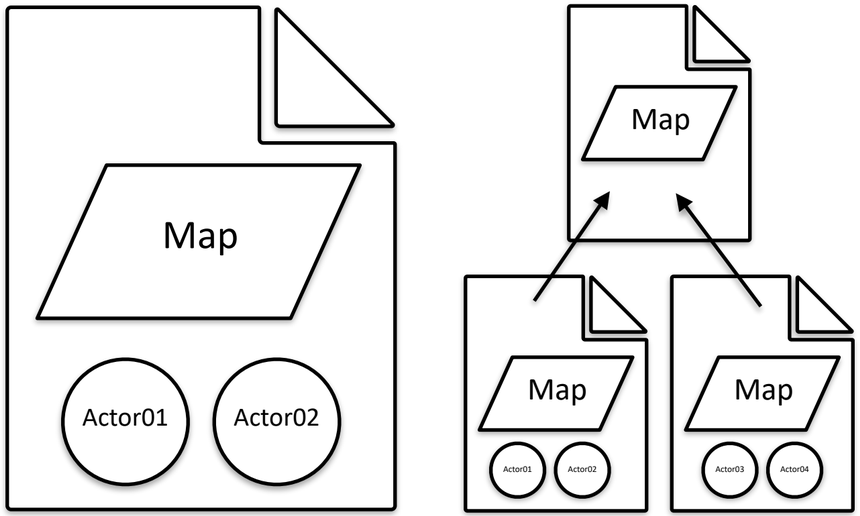

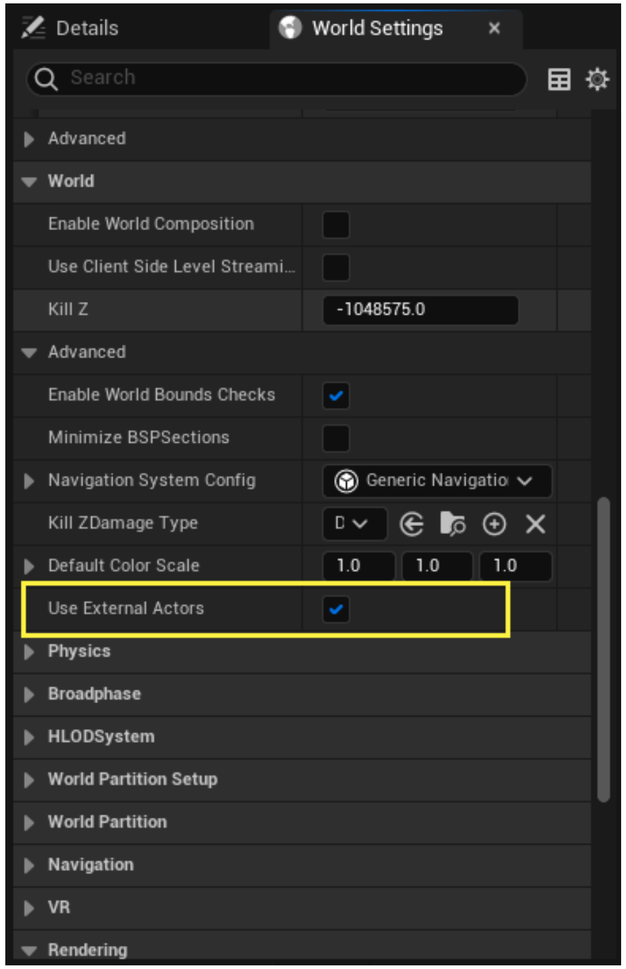

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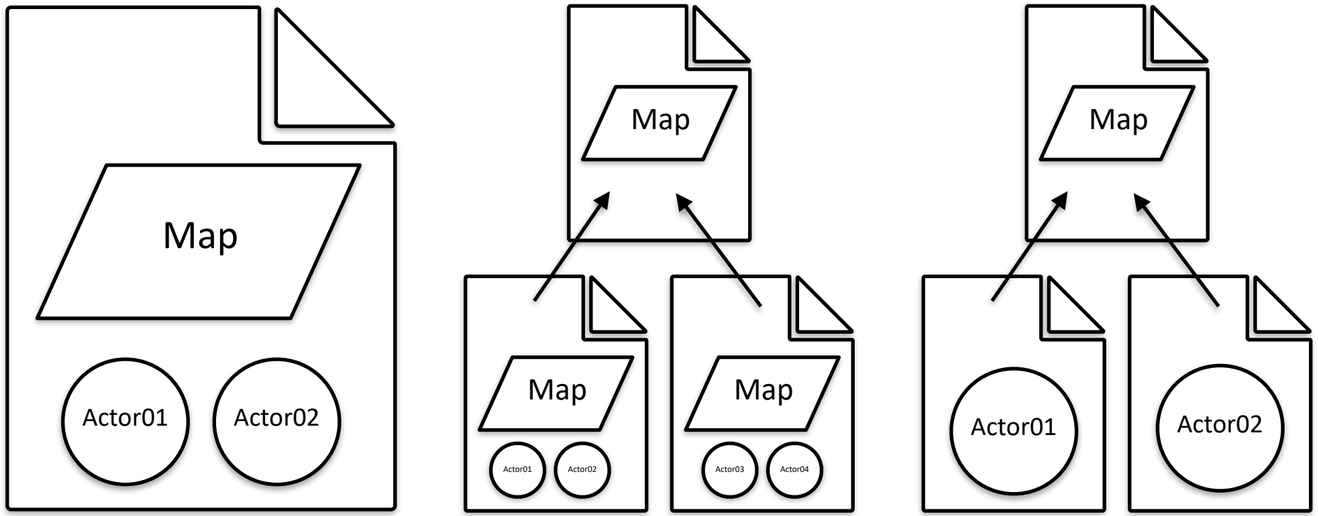

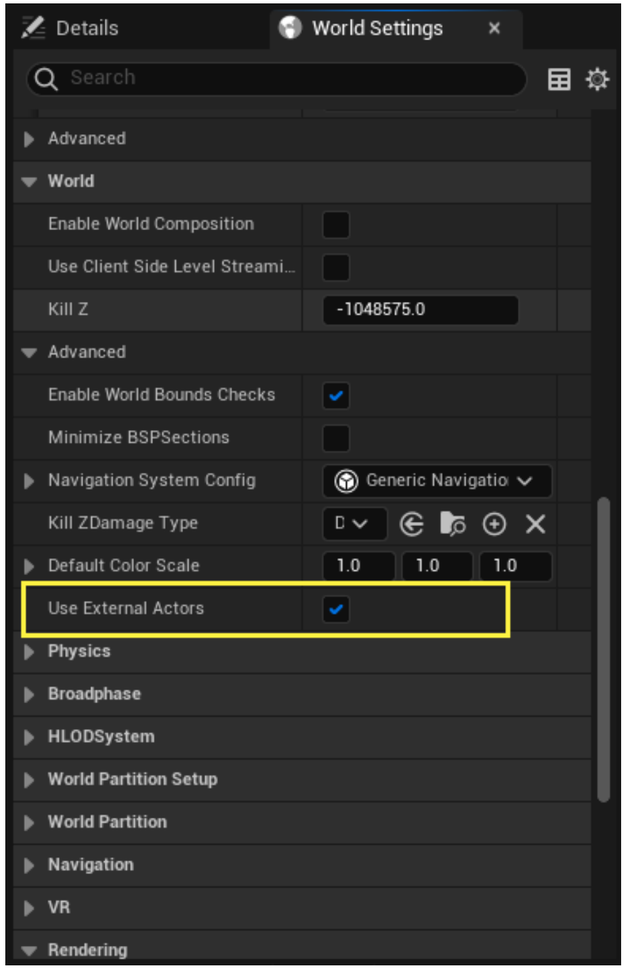

Anatomy Of An External Actor File

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External Actor Directory

Owning Level Path

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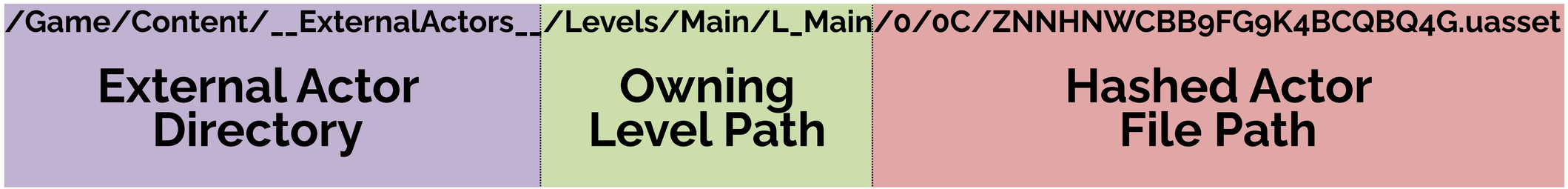
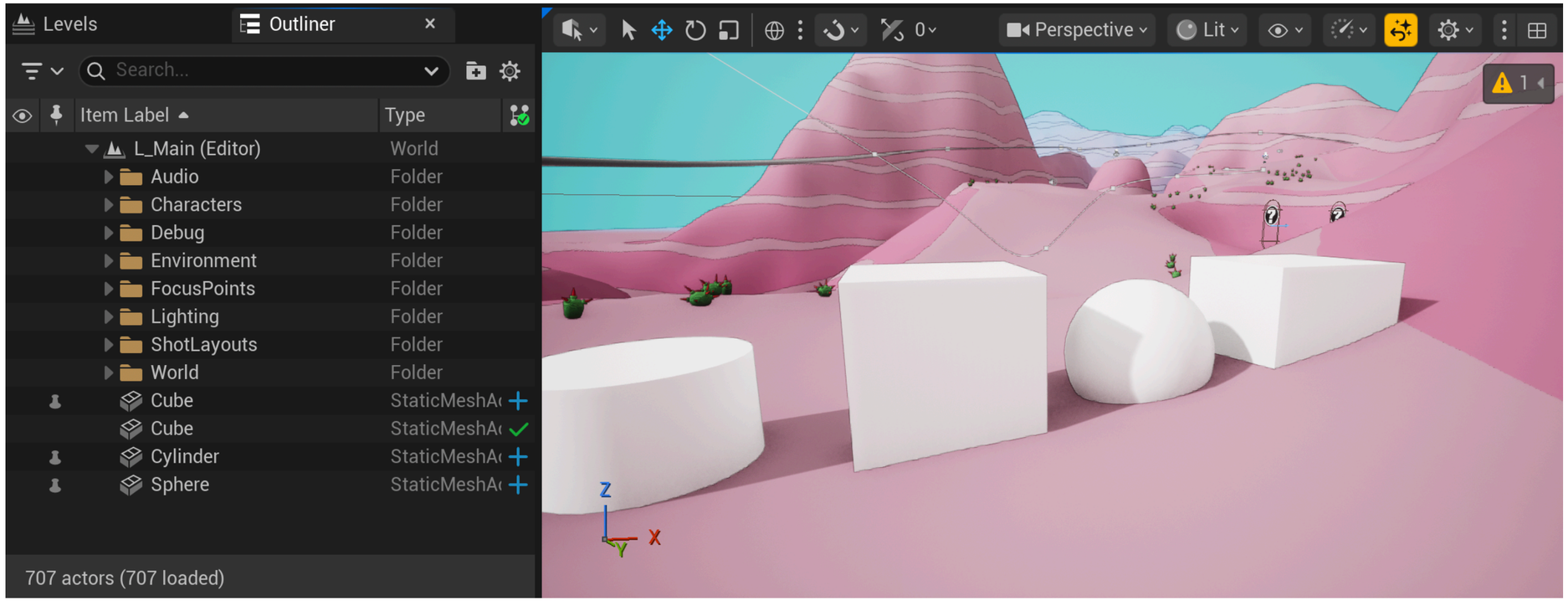


Managing External Actors

- Keeping your comfortable p4 or Git workflow can be painful
- Seems worse than it is though



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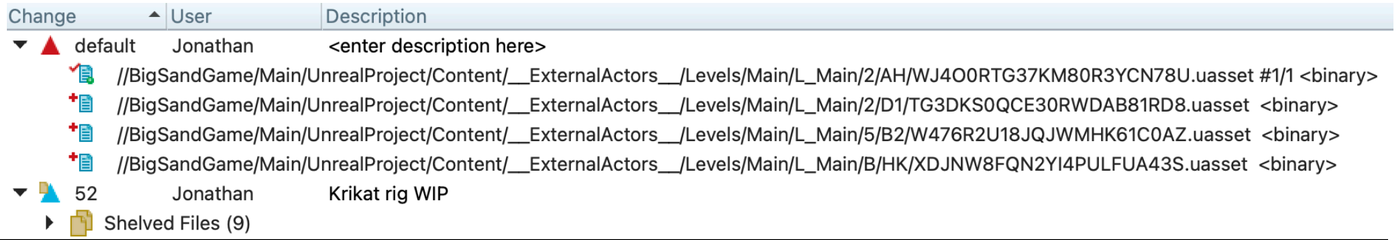

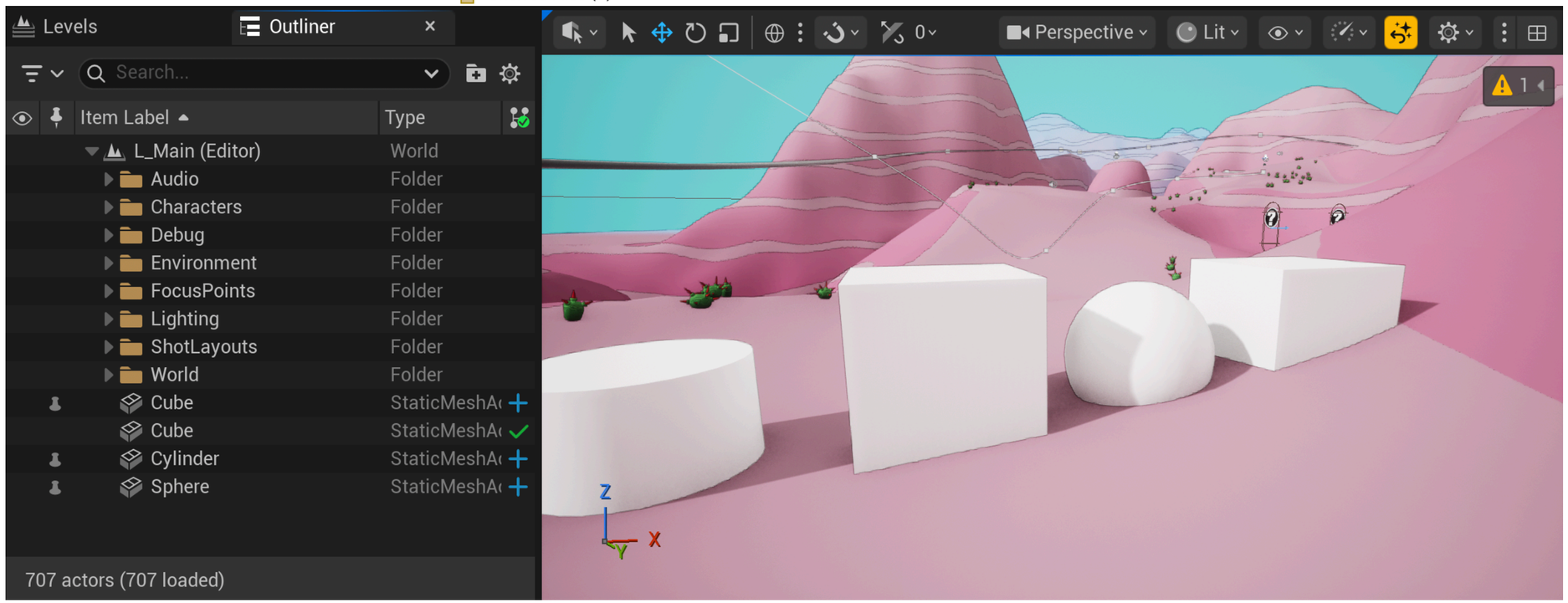

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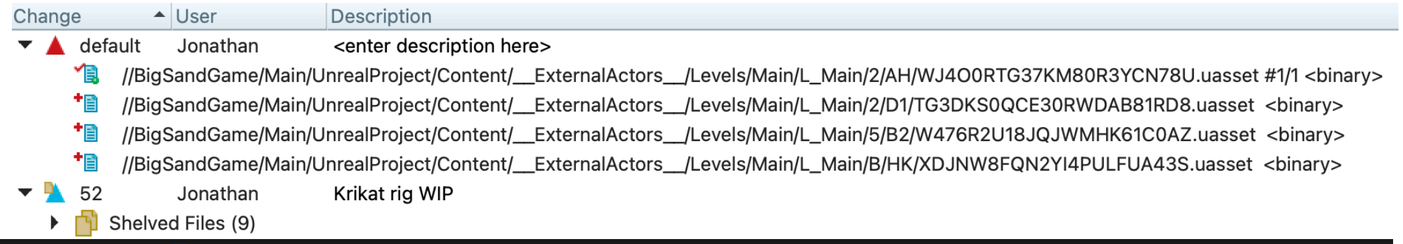

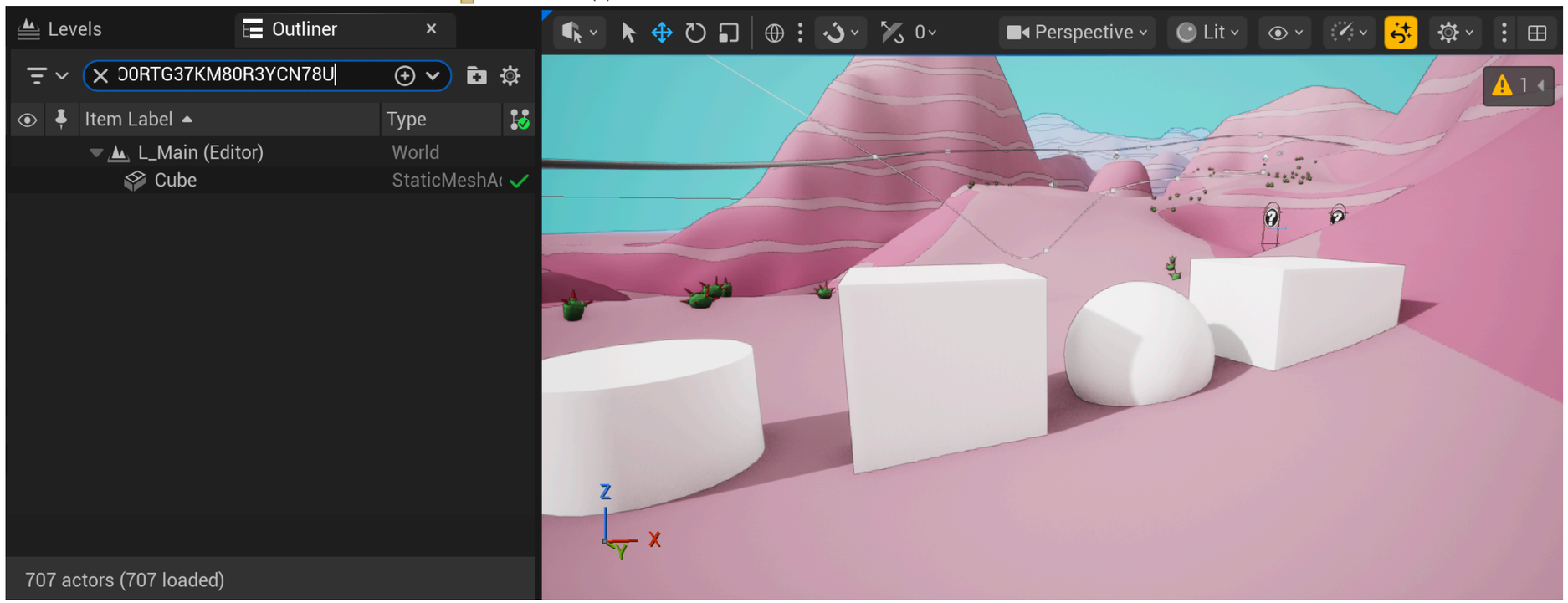

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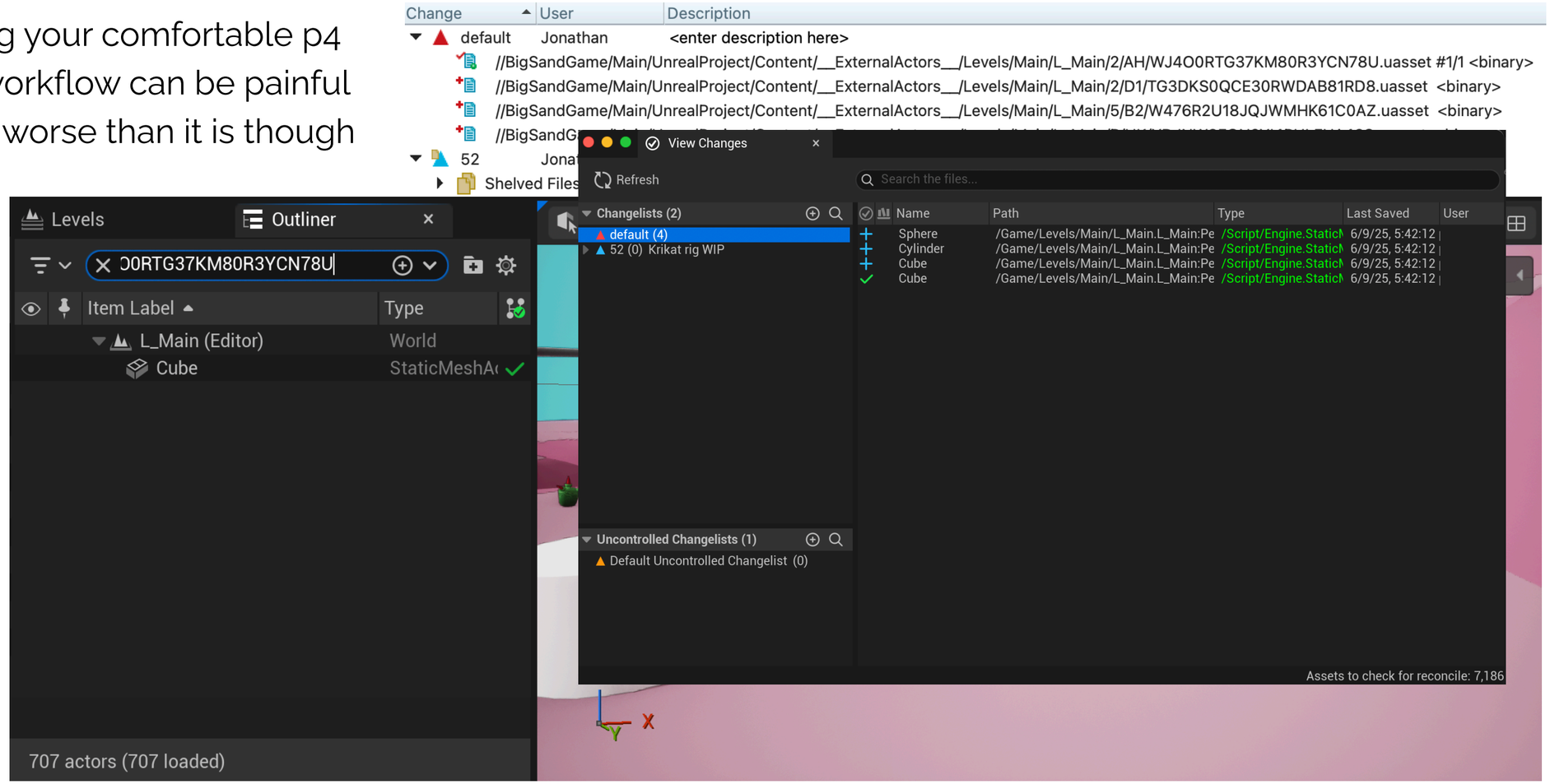

Workflow Considerations When Working With OFPA

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- ✓ Great In-Editor VCS Support
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- ✓ Reduced Checkout Collisions
- ✓ More Granular Checkins
- ✓ Great In-Editor VCS Support
- ✗ More Complicated Checkout Collisions
- ✗ Nonsense Changelist Contents
- ✗ Required In-Editor Workflows

A Tool For OFPA Actor Lookup

```
def find_external_actor(search_file, log_file):
	def get_map_filename(f):
		search_file_components = f.split("/")
		map_file = search_file_components[search_file_components.index("__ExternalActors__")+1:len(search_file_components)-3]
		return "/Game/{}.umap".format("/".join(map_file))
	map_file_path = get_map_filename(search_file)
	unreal.log_warning("Deduced external actor from map: {}".format(map_file_path))
	unreal.EditorLoadingAndSavingUtils.load_map(map_file_path)

	def get_external_actor_map():
		ed_actor_subsys = unreal.get_editor_subsystem(unreal.EditorActorSubsystem)
		actors = ed_actor_subsys.get_all_level_actors()
		return {str(unreal.AssetRegistryHelpers.create_asset_data(a).package_name): a for a in actors}
	external_actor_map = get_external_actor_map()

	f = open(log_file, "w")
	for k, v in external_actor_map.items():
		package_path = unreal.AssetRegistryHelpers.create_asset_data(v).package_name
		unreal.log_warning(package_path)
		path = pathlib.Path(str(package_path).replace("/Game", unreal.Paths.project_content_dir()) + ".uasset")
		last_modified = datetime.datetime.fromtimestamp(path.stat().st_mtime)
		f.write("{}: {} - {} modified at {}\n".format(k, v.get_actor_label(), v.get_full_name(), last_modified))
	f.close()

	found_actor = external_actor_map[search_file.replace("Content", "/Game").replace(".uasset", "")]
	unreal.log_warning("FOUND EXTERNAL ACTOR: {} - {}".format(found_actor.get_actor_label(), found_actor.get_full_name()))

find_external_actor(sys.argv[1])
```

"C:\PathToUnreal\UnrealEditor-Cmd.exe" "C:\PathToProject\Project.uproject" -stdout -FullStdOutLogOutput -run=pythonscript
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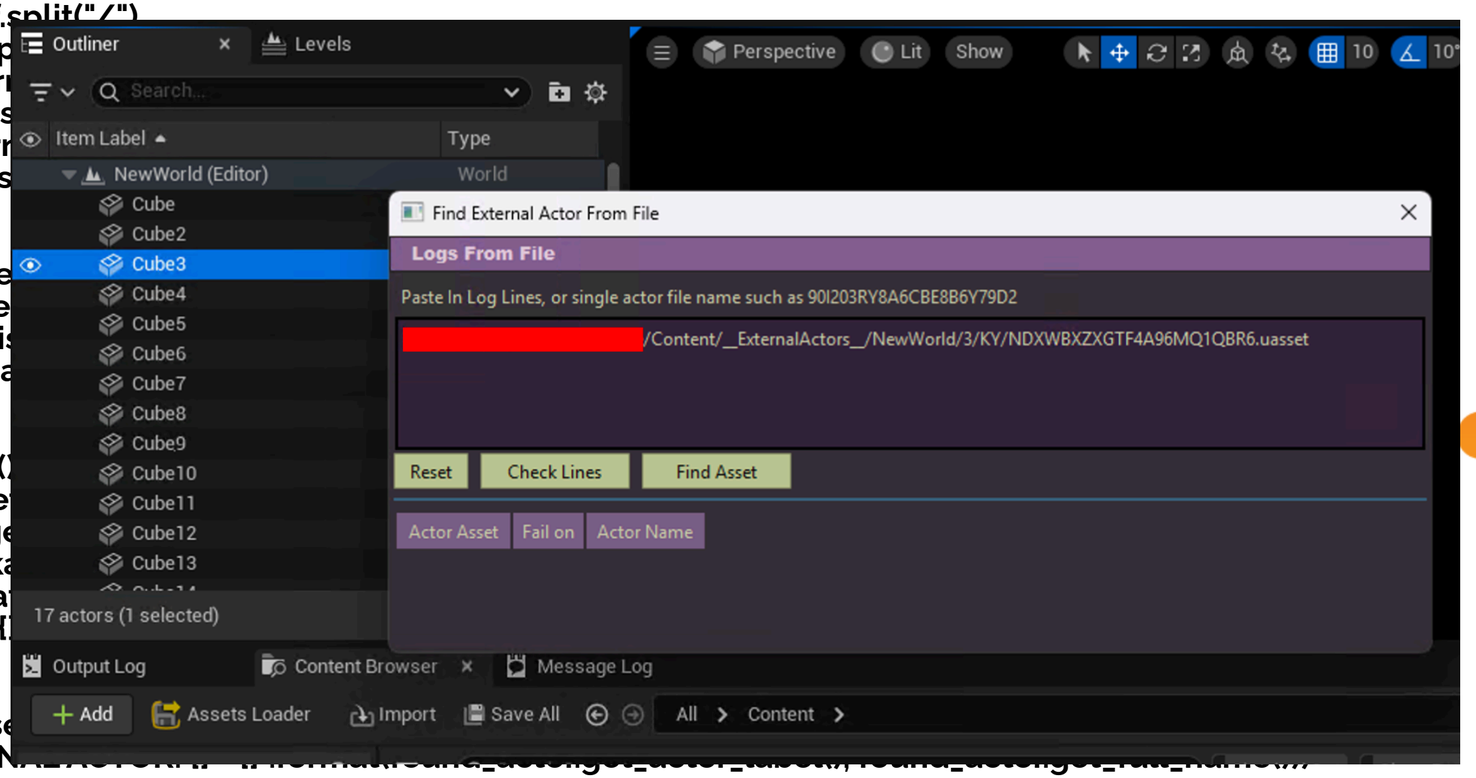

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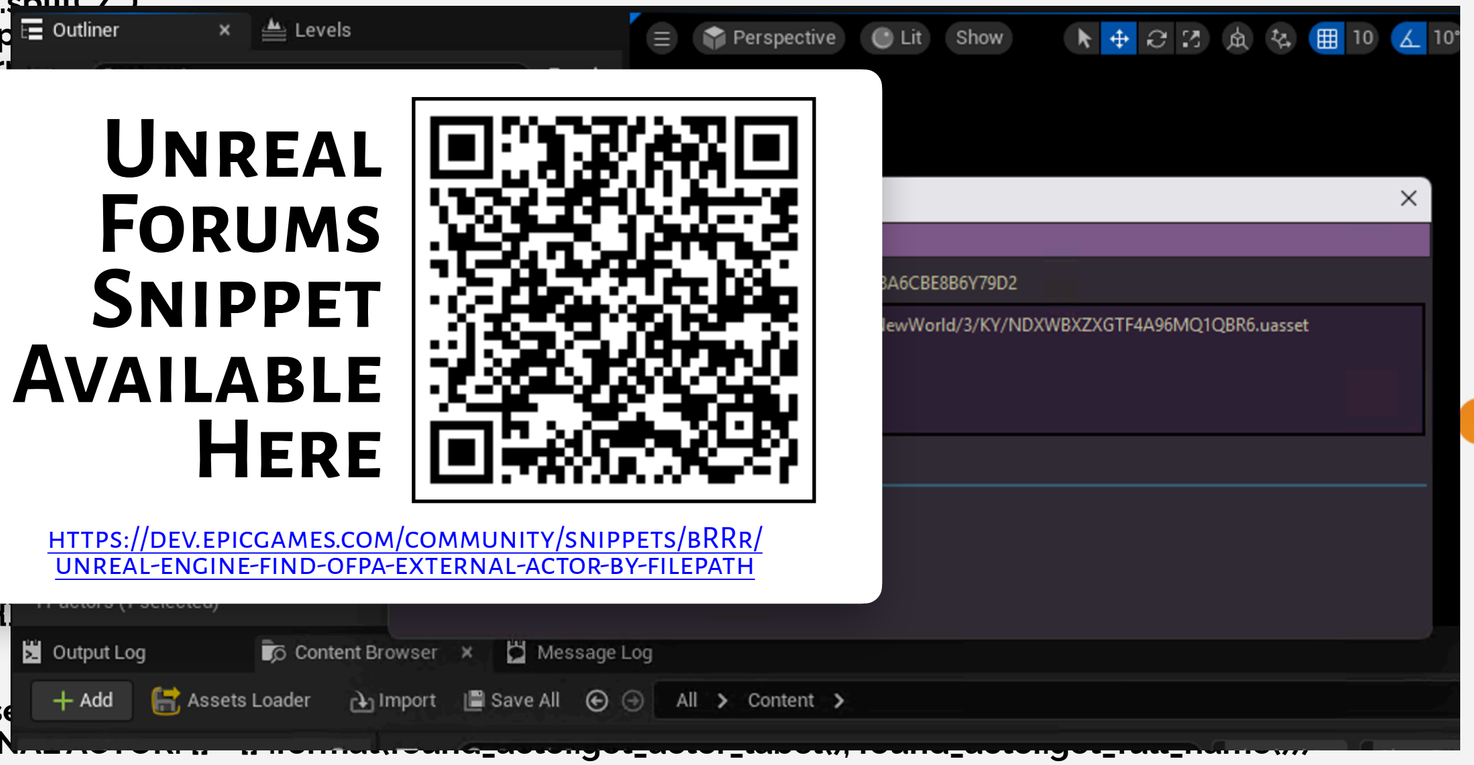

Unreal Forums Snippet Available Here

https://dev.epicgames.com/community/snippets/bRRr/unreal-engine-find-ofpa-external-actor-by-filepath

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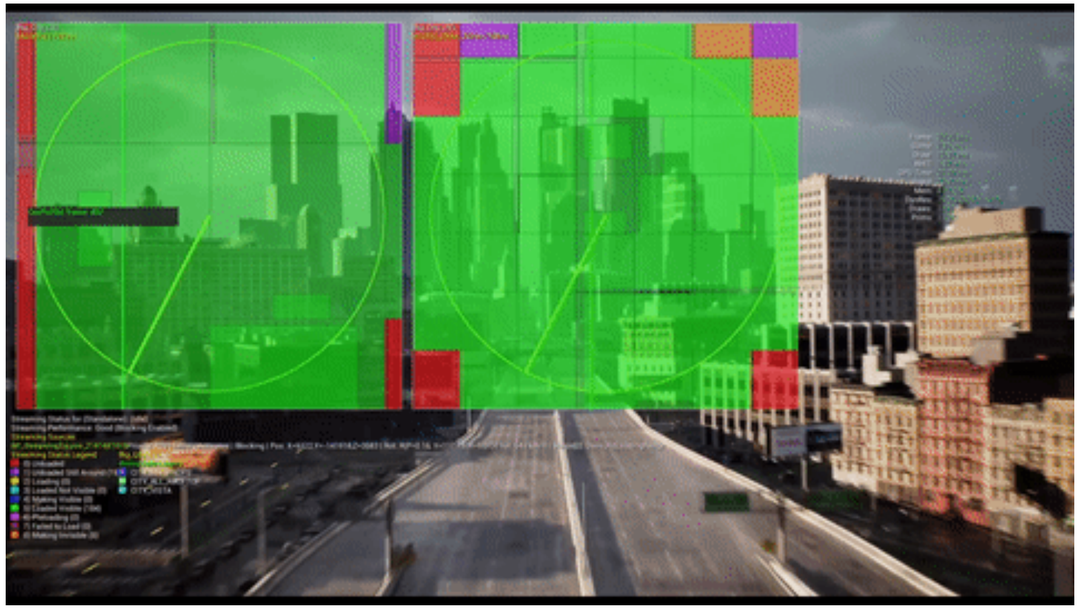
Grids

- Open worlds typically divvy up the world into “chunks” that can be streamed in and out as the player navigates the game world

- A world partitioned map may contain one or more **grids**, which each contain automatically portioned **cells** across which content is divided

- Thought should be put into the initial configuration which should account for:
  - Content density
  - Available memory
  - World layout
  - Player movement speed
- Avoid micro-management



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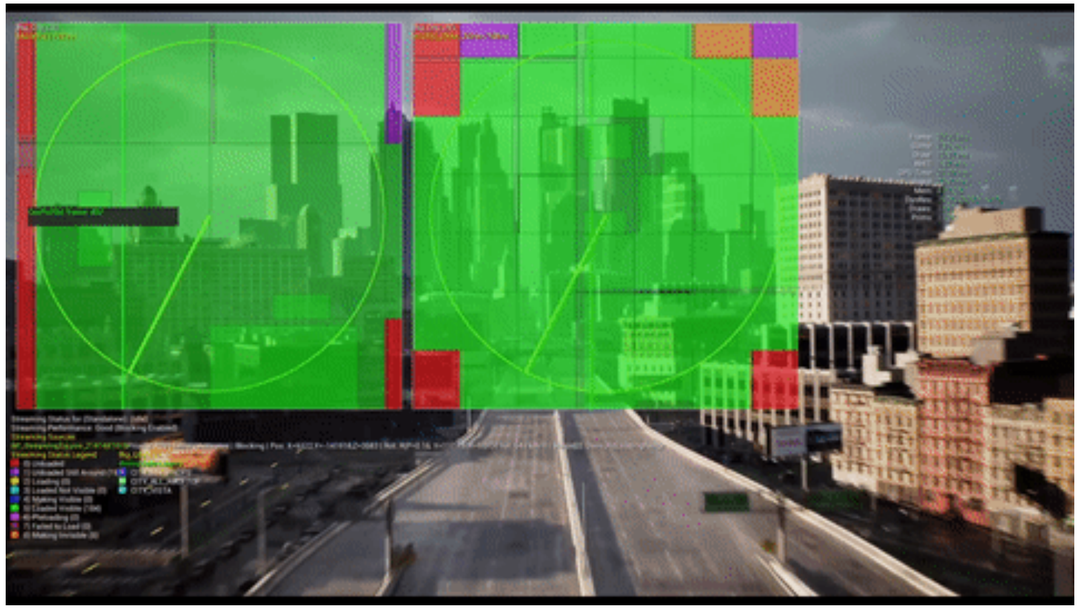

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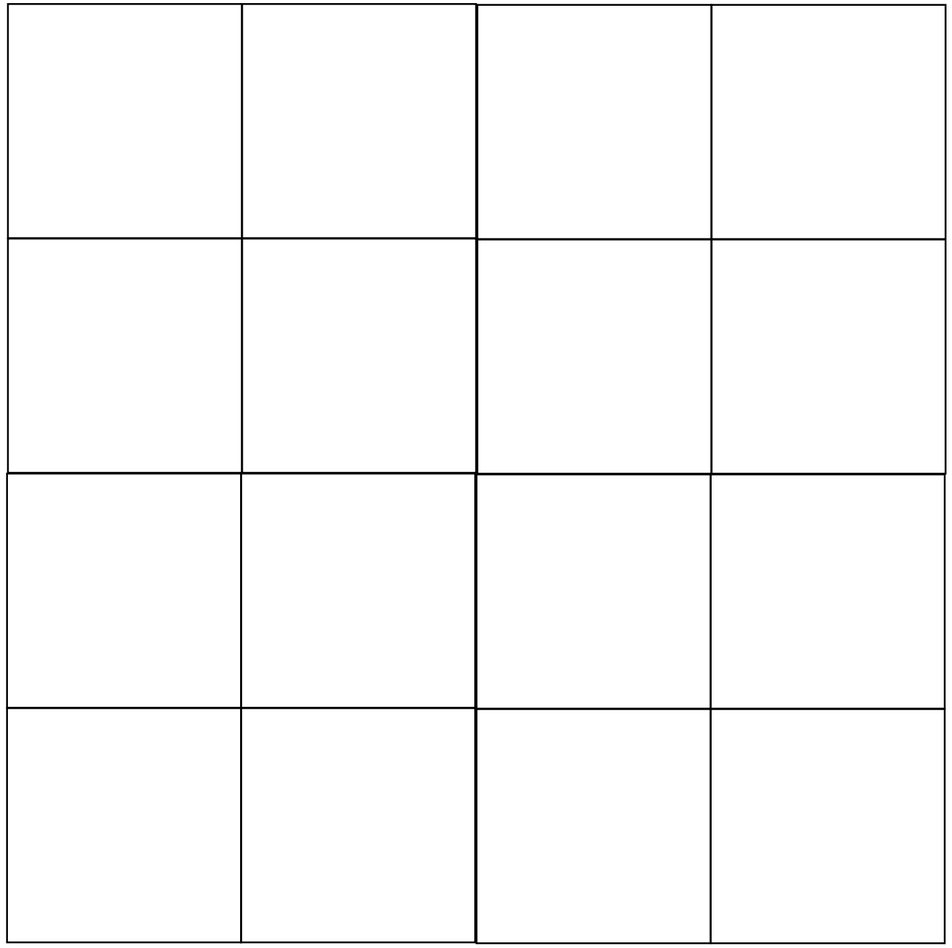
Streaming Generation

- Process of building the data structures to assign actors into logical groups for streaming purposes
- All actors will be assigned to a streaming level based a number of factors, including the cell of the runtime grid they fall within
- The resulting work is used to marshal actors to the “streaming levels” used at runtime
- Occurs during cook in builds and on-the-fly during PIE sessions



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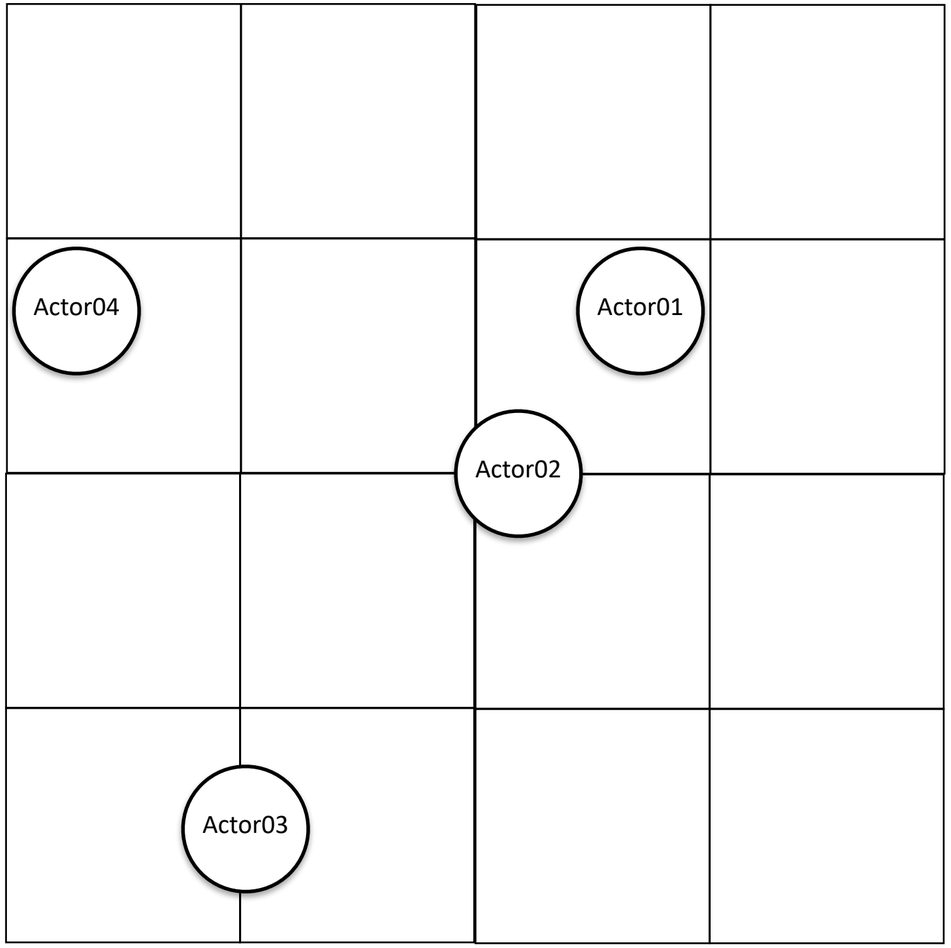

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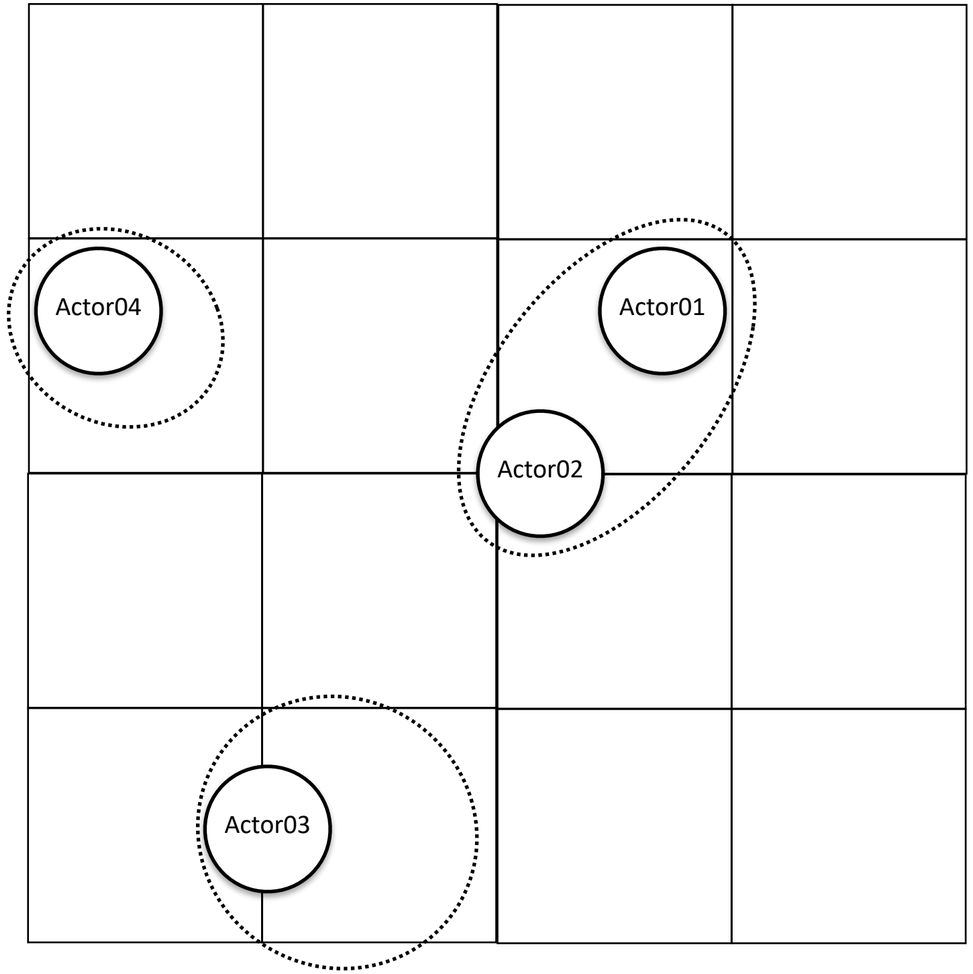
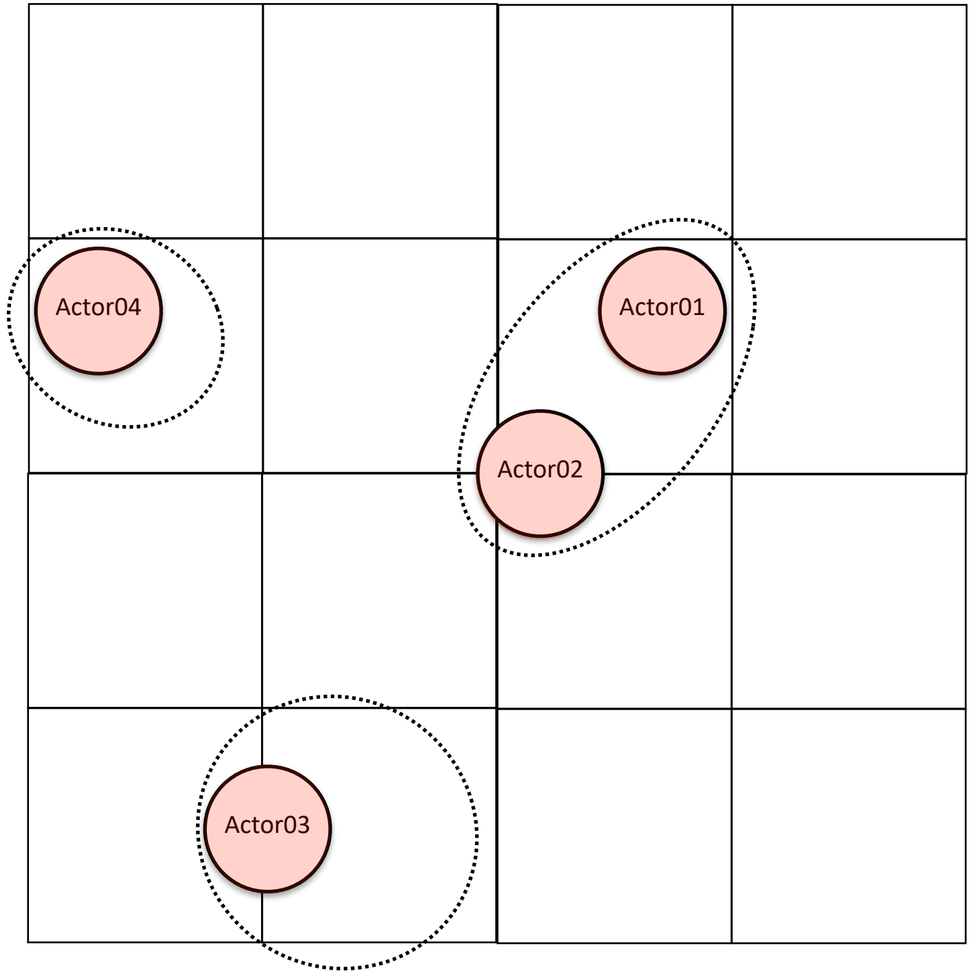


Runtime Grid Streaming Rules

- Streaming levels are brought up for consideration when their requirements are met

- Streaming states can be one of:
  Unloaded, **Loaded**, or **Activated**

- **BeginPlay** will be fired as soon as they are streamed into the world
- **EndPlay** will be fired as they are streamed out (with the reason of **RemovedFromWorld**)



Runtime Grid Streaming Rules

- Streaming levels are brought up for consideration when their requirements are met

- Streaming states can be one of:
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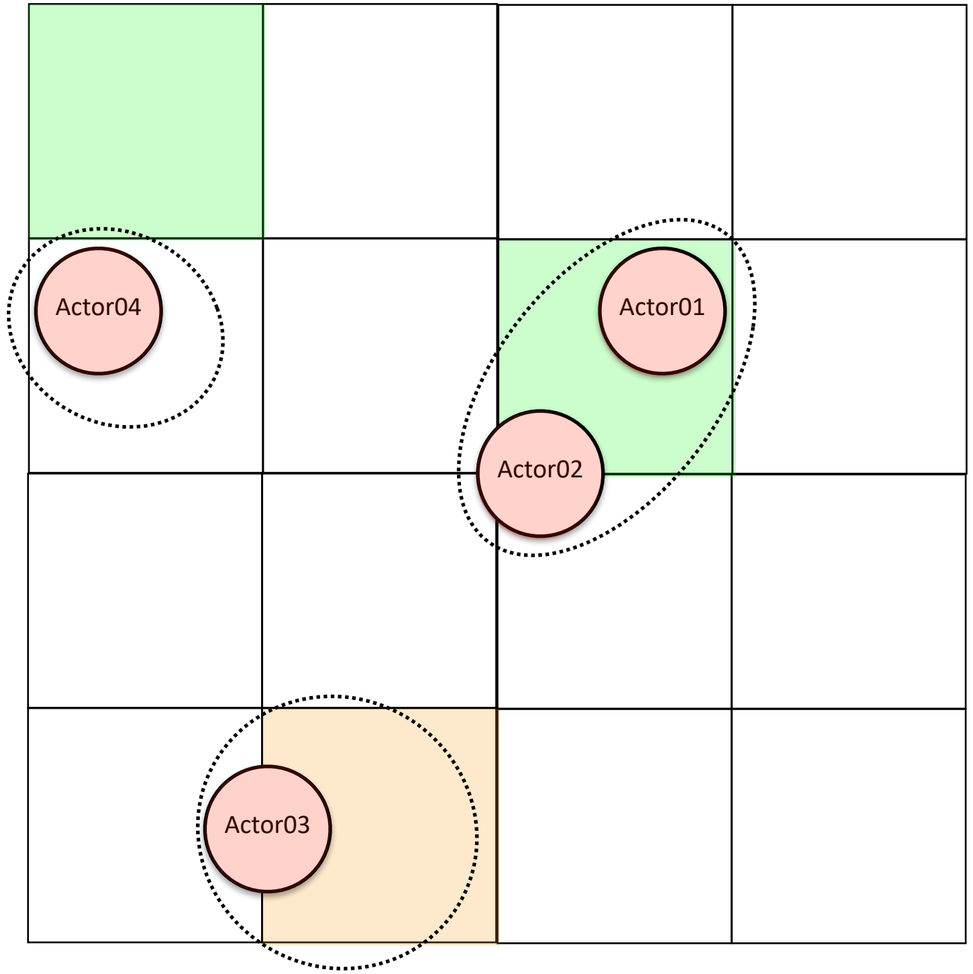

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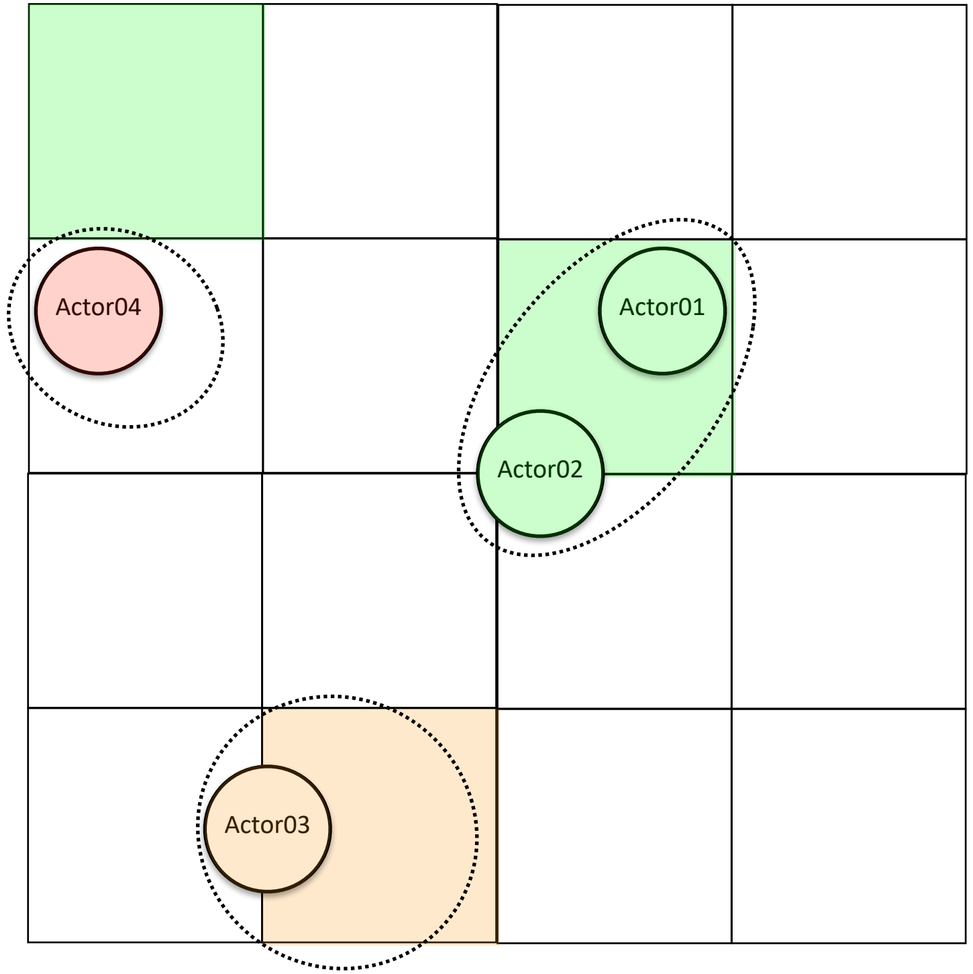

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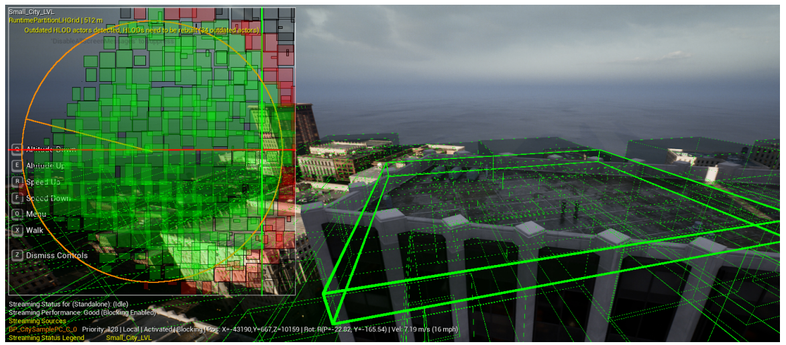
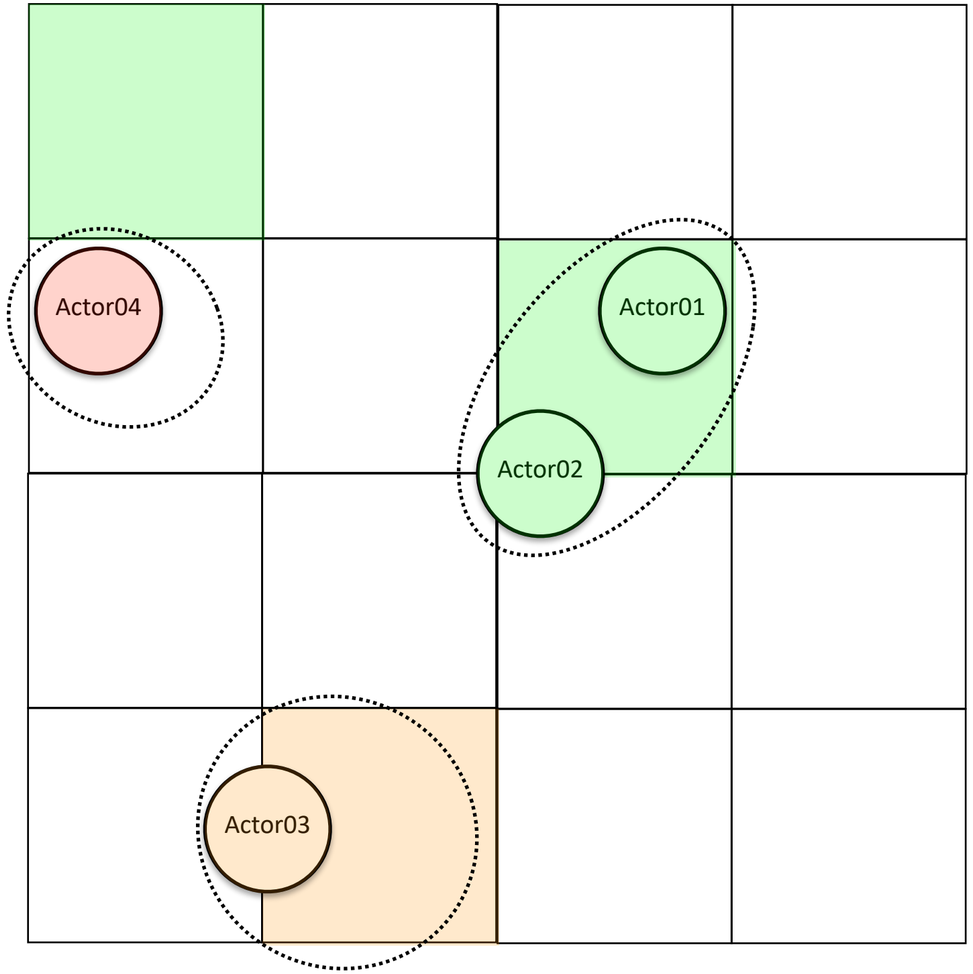




Dehydrating Actors For Streaming

right up there with other programmer phrases like “ensure all children are orphaned before destroying world”

- Actor descriptors are used to represent actors within the World Partition system
- They are managed as: **FWorldPartitionActorDescriptor** and **FWorldPartitionActorDescriptorInstance**
- Effectively handled separately from the actors that are managed by the world itself
- They retain a relatively limited set of instance information

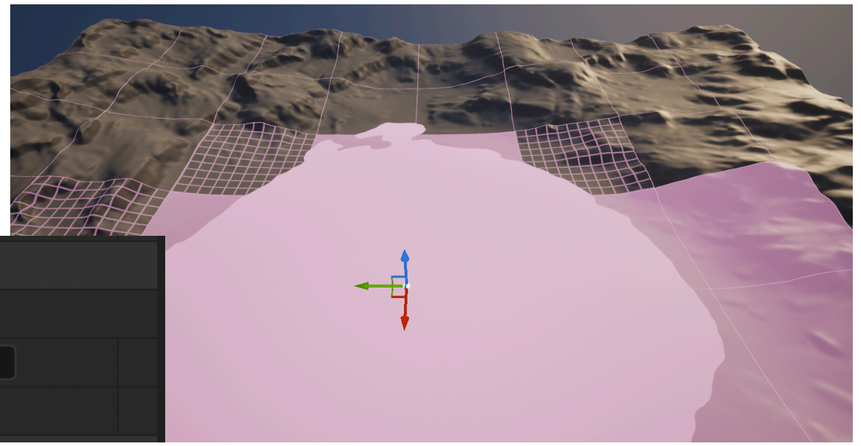
```
// Persistent
FGuid                       Guid;
FTopLevelAssetPath          BaseClass;
FTopLevelAssetPath          NativeClass;    // Not serialized, comes from initialization data
FName                       ActorPackage;   // Not serialized, comes from initialization data
FSoftObjectPath             ActorPath;      // Not serialized, comes from initialization data
FName                       ActorLabel;
FTransform                  ActorTransformRelative;        // Relative transform for actors with parent actor, actor-to-world transform otherwise
FWorldPartitionRelativeBounds RuntimeBoundsRelative;  // Runtime bounds relative to actor-to-world transform
FWorldPartitionRelativeBounds EditorBoundsRelative;   // Editor bounds relative to actor-to-world transform
FName                       RuntimeGrid;
bool                        bIsSpatiallyLoaded;
bool                        bActorIsEditorOnly;
bool                        bActorIsRuntimeOnly;
bool                        bActorIsMainWorldOnly;
bool                        bActorIsHLODRelevant;
bool                        bActorIsListedInSceneOutliner;
bool                        bIsUsingDataLayerAsset; // Used
FSoftObjectPath             HLODLayer;
TArray<FName>               DataLayers;
FSoftObjectPath             ExternalDataLayerAsset;
TArray<FGuid>               References;
TArray<FGuid>               EditorOnlyReferences; // Refere
TArray<FName>               Tags;
FPropertyPairsMap           Properties;
FName                       FolderPath;
FGuid                       FolderGuid;
FGuid                       ParentActor; // Used to validat
FGuid                       ContentBundleGuid;

// Transient
UClass*                     ActorNativeClass;
FName                       ActorName;
FString                     ActorNameString;
FString                     ActorLabelString;
FString                     ActorDisplayClassNameString;
UActorDescContainer*        Container;
FTransform                  ActorTransform; // Current acto
FBox                        RuntimeBounds;  // Current runt
FBox                        EditorBounds;   // Current edit
bool                        bIsDefaultActorDesc;
bool                        bHasValidRelativeBounds;
```

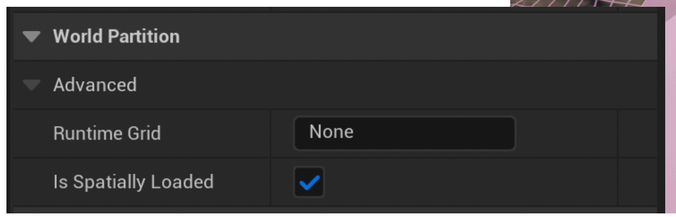
```
protected:
    TObjectPtr<UActorDescContainerInstance>     ContainerInstance;

    mutable uint32                              SoftRefCount;
    mutable uint32                              HardRefCount;
    TOptional<FDataLayerInstanceNames>          ResolvedDataLayerInstanceNames;
    bool                                        bIsForcedNonSpatiallyLoaded;
    bool                                        bIsRegisteringOrUnregistering;
    mutable FText*                              UnloadedReason;
    mutable int32                               AsyncLoadID;

    // Instancing Path if set
    TOptional<FSoftObjectPath>                  ActorPath;

    mutable TWeakObjectPtr<AActor>              ActorPtr;
    FWorldPartitionActorDesc*                   ActorDesc;

    TObjectPtr<UActorDescContainerInstance>     ChildContainerInstance;
```

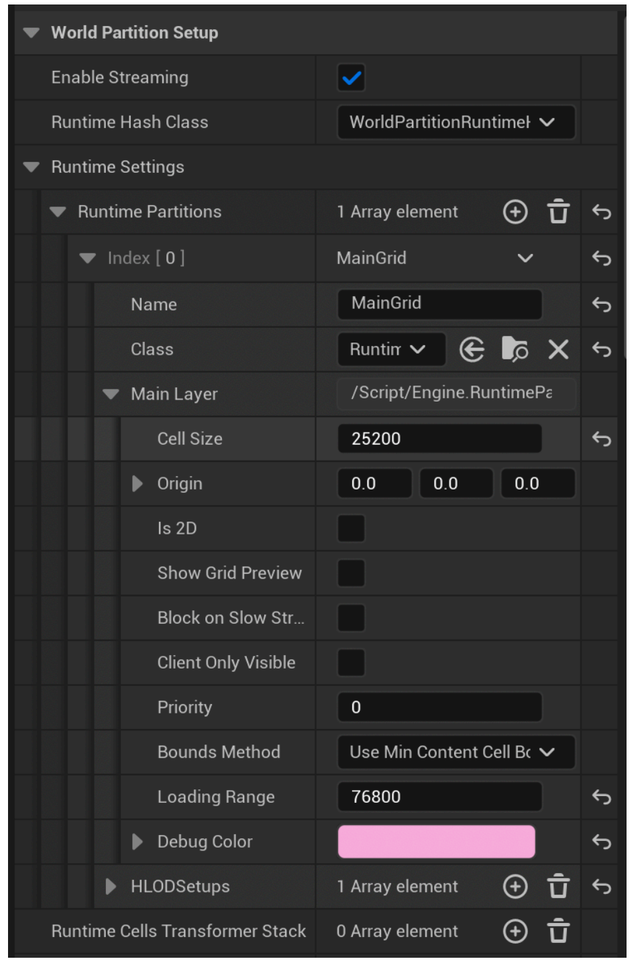
Grids & Actor Streaming Configuration

- **World Settings:**
  - Runtime Hash Class
  - Runtime Partitions:
    - Cell size, origin, priority, loading range, slow streaming block, etc.
    - Top partition is considered default grid
- **Actor Settings:**
  - Runtime grid property (WHY IS IT FREE TEXT?? *map check helps*)
  - IsSpatiallyLoaded (hard to keep track of, can create ref chain)

- Use grid previews and block on slow streaming to debug setup

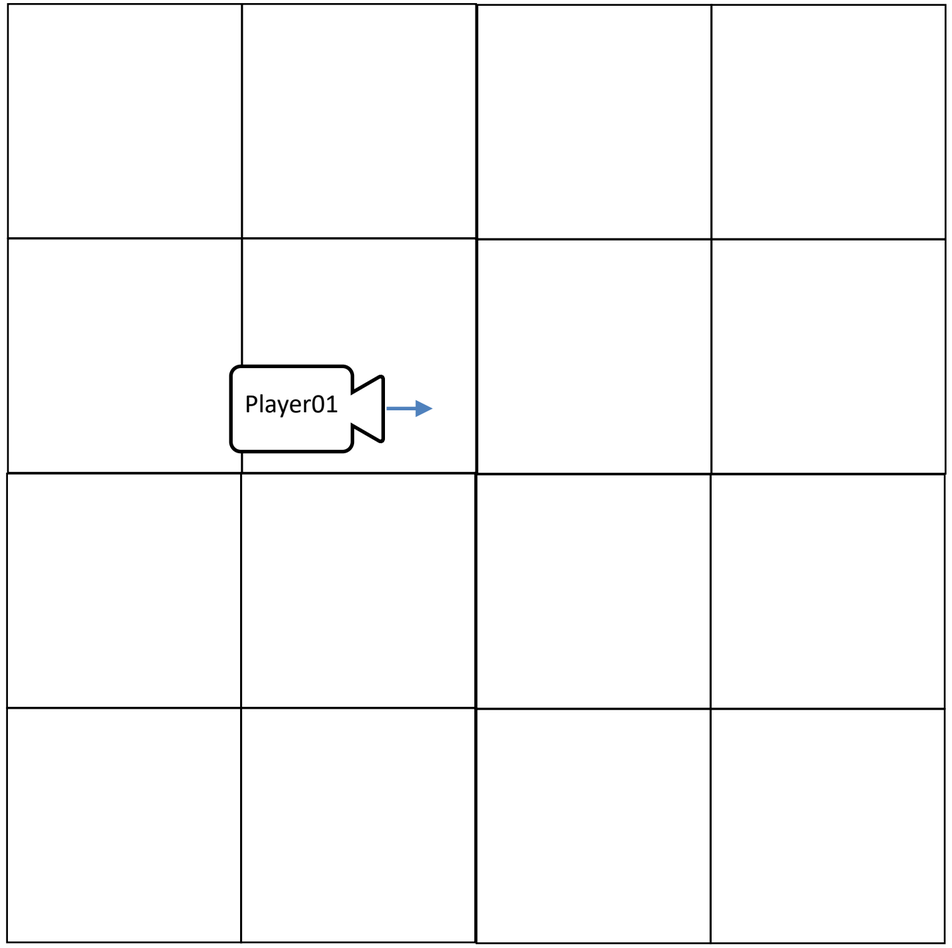






Streaming Sources

- Streaming sources define the range of grid cells to consider at runtime for streaming
- Streaming sources must register to the World Partition subsystem as a streaming source provider
- Sources can override default grid loading ranges and define streaming source shapes for more complex behaviour management
- Can be setup to target different grids and states
- Having multiple streaming sources can be useful when preloading areas of the world such as:
  - Warming up an impending teleport
  - Faraway sequence cuts



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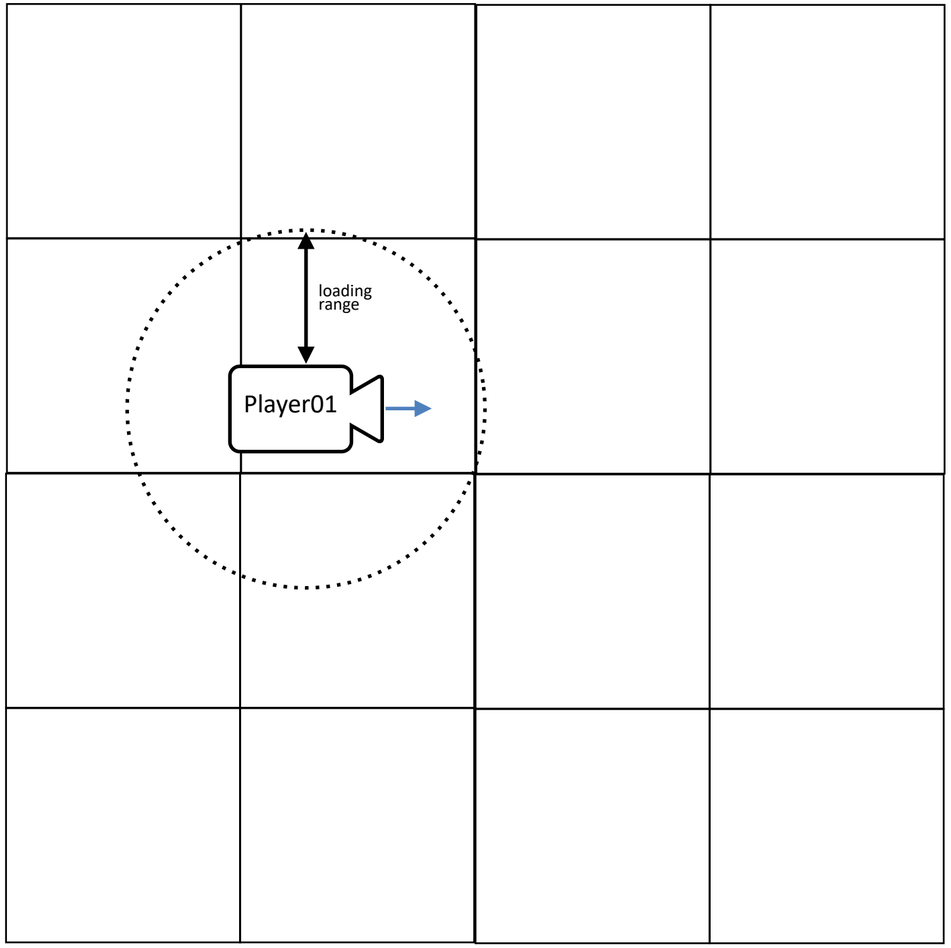

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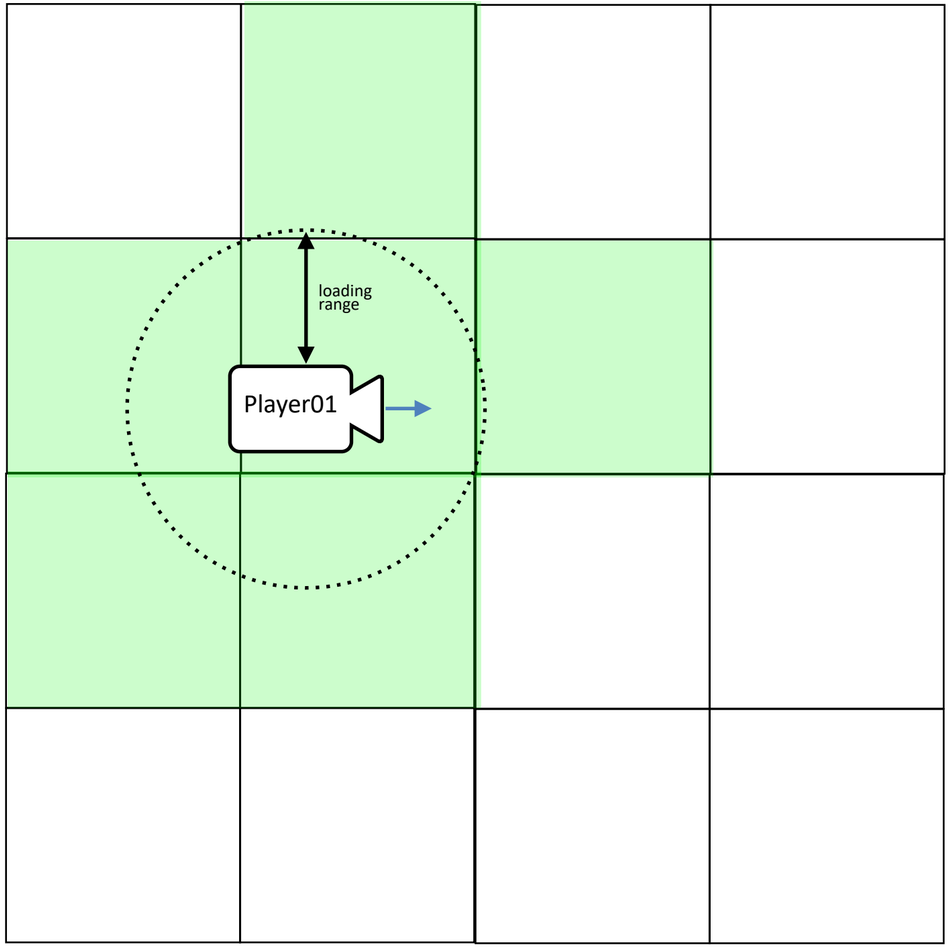

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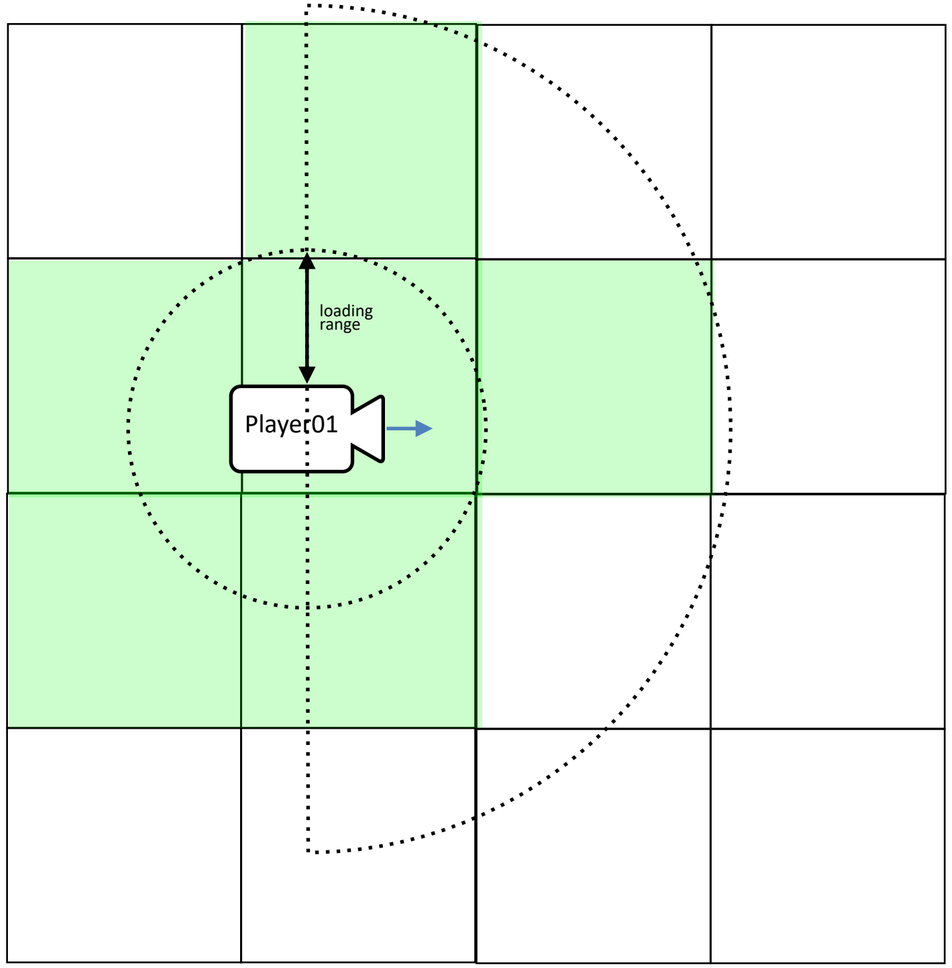

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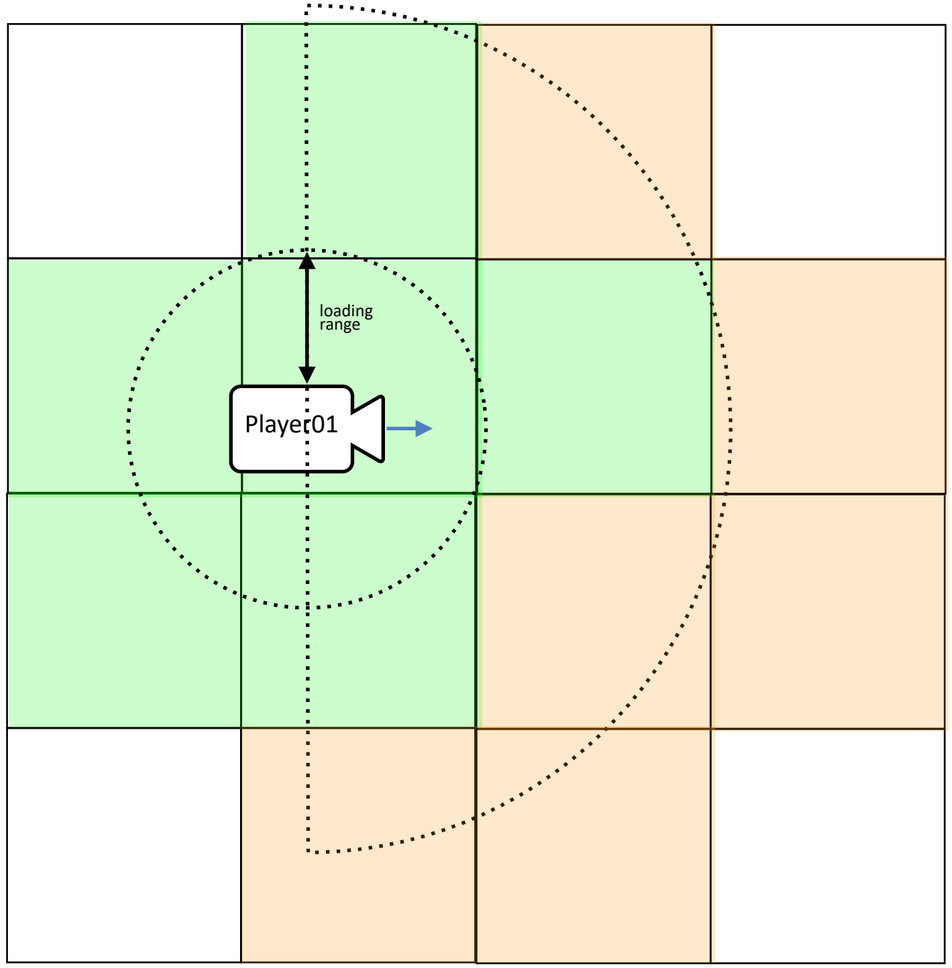

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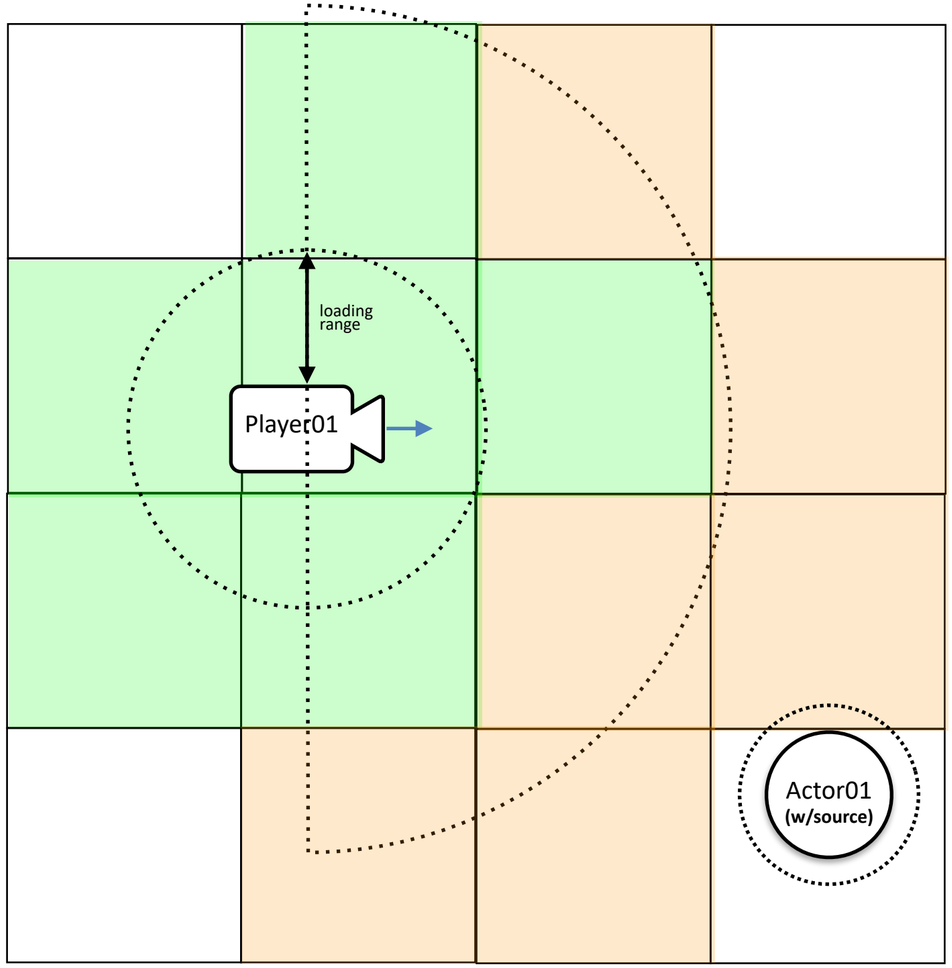

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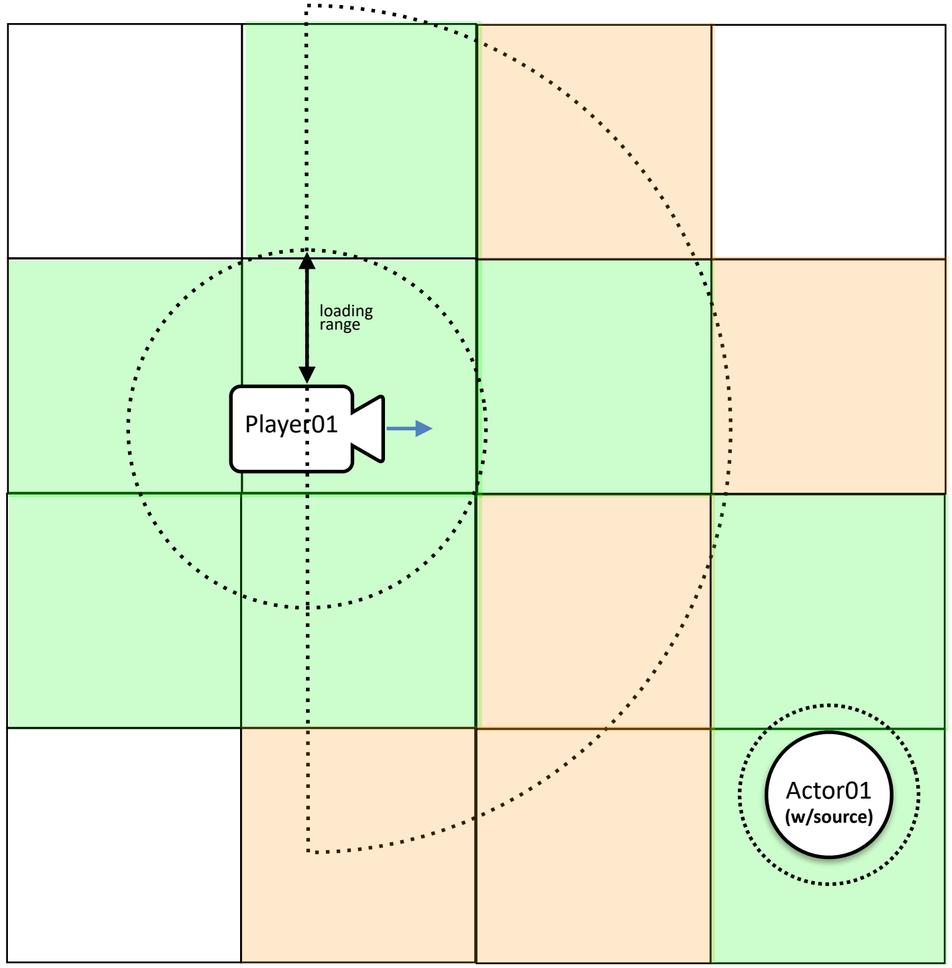
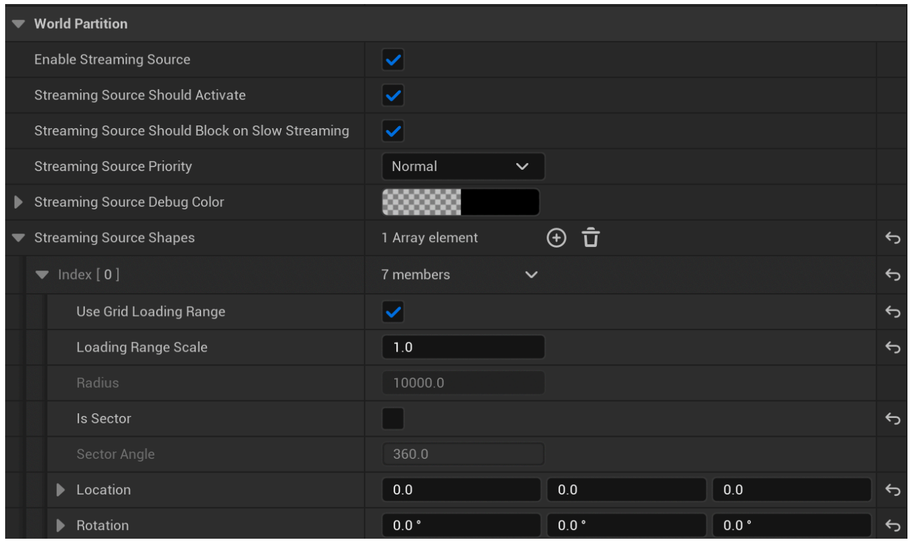


Configuring Streaming Sources

- **APlayerController** registers itself as a streaming source by default using the player camera manager's view target actor's "eyes"
- **UWorldPartitionStreamingSourceComponent** provides its owning actor's location/rotation



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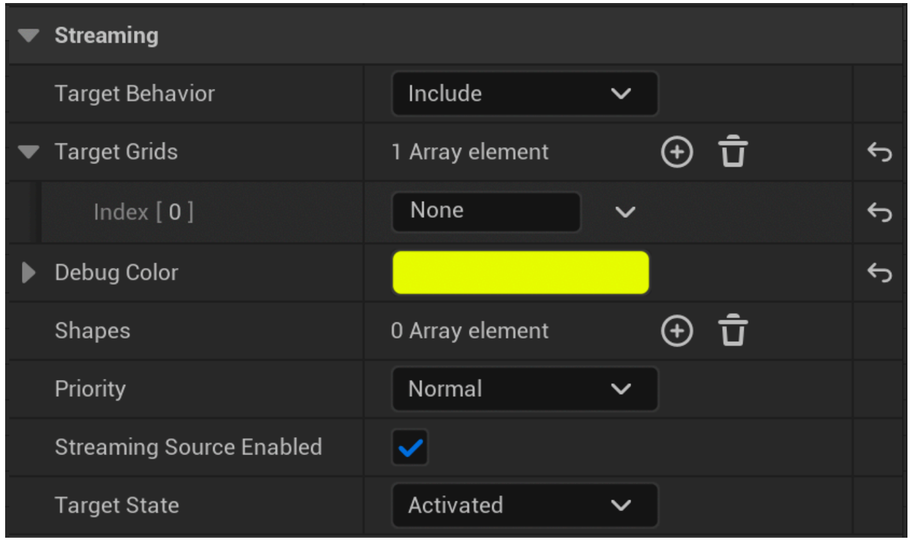
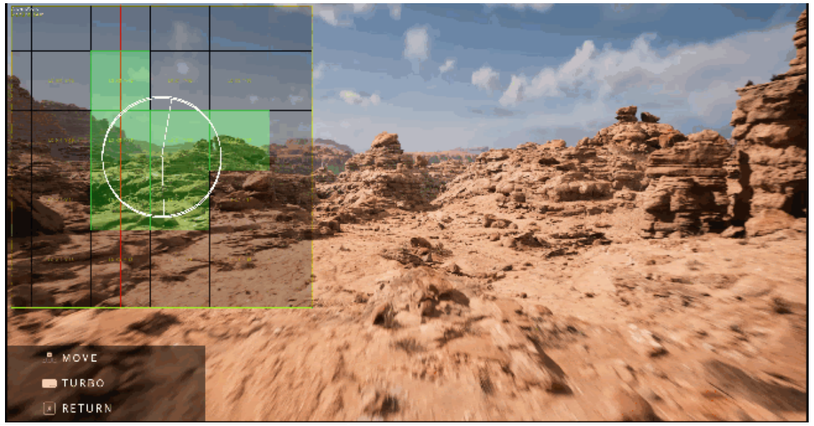
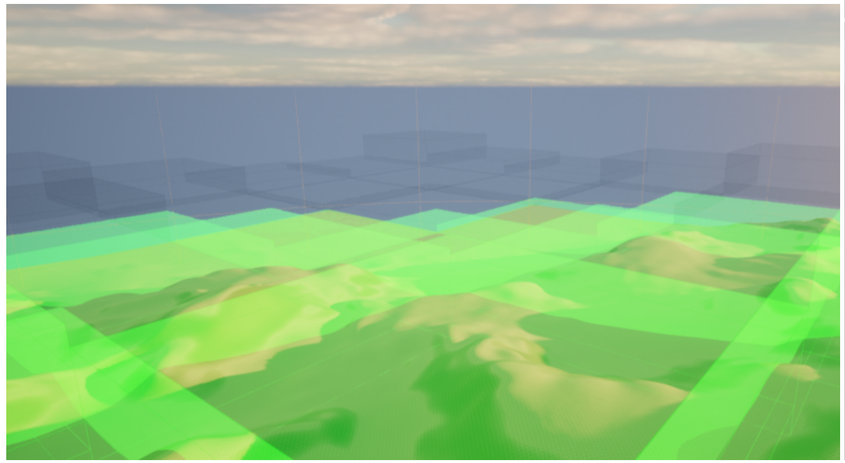
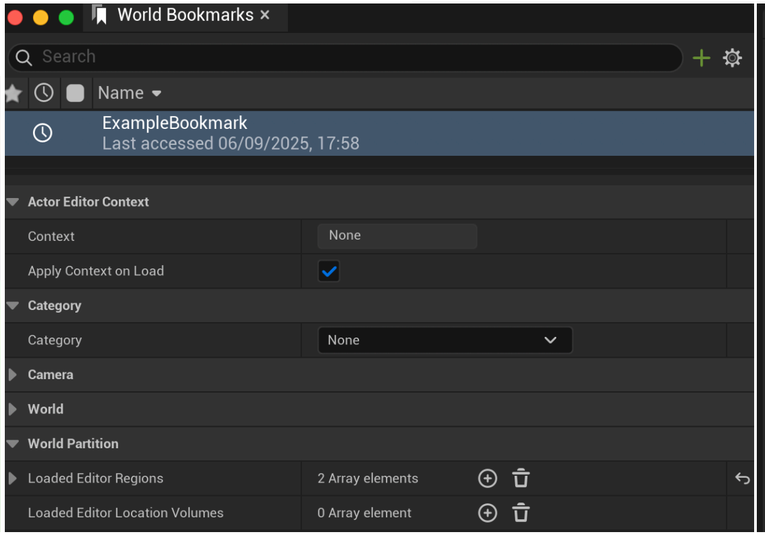


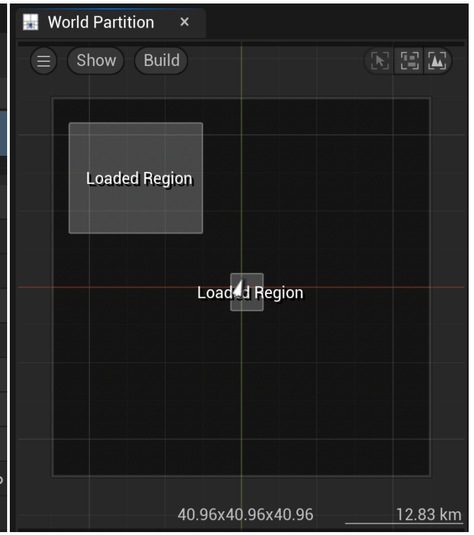
Tips For Working With Grids

- Make use of the inbuilt 2D/3D visualisation for debugging
- Use “block on slow streaming” to pinpoint streaming problems
- Sub-World Partitions can be used for complex world setups
- World Partition Editor & Bookmarks help with editing
- Foliage & landscape auto-partition with streaming proxies
- Actors will not persist data on streaming out completely
- Actors are streamed in and out with their original cell
- Keep actor bounds to a minimum









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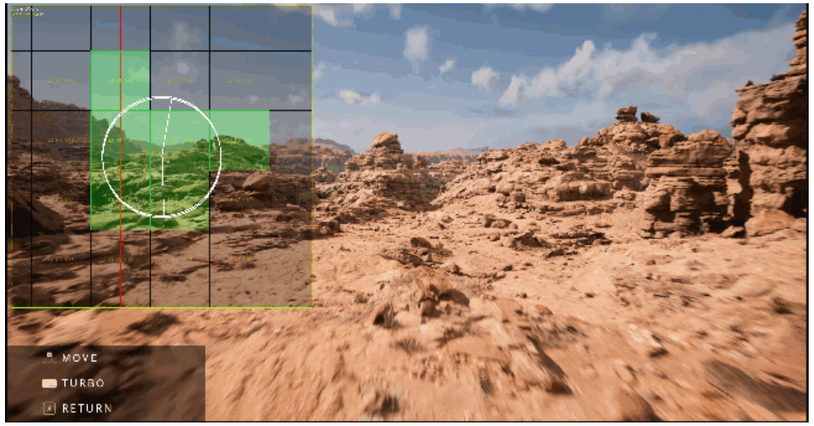

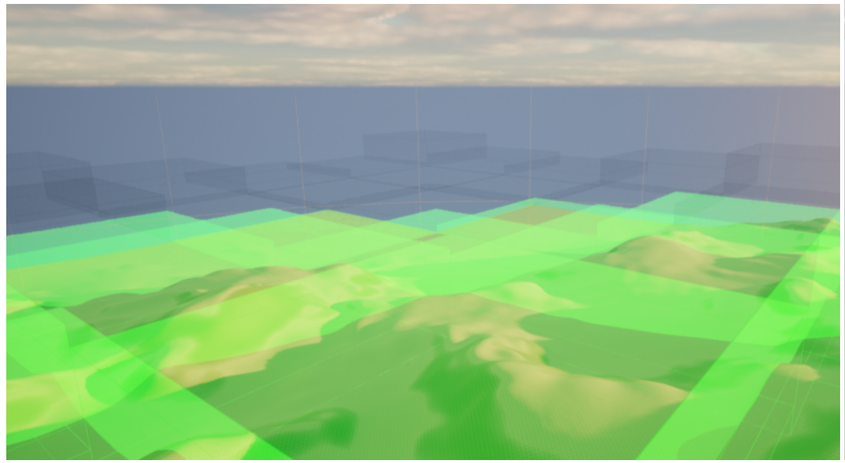

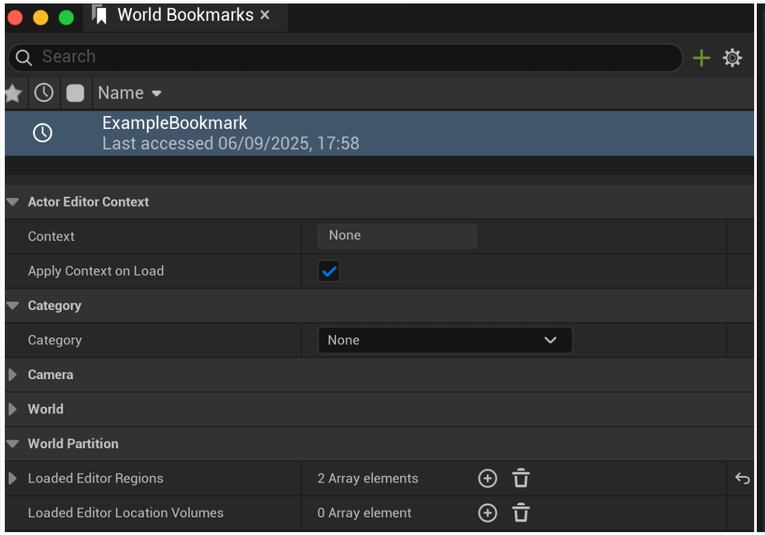

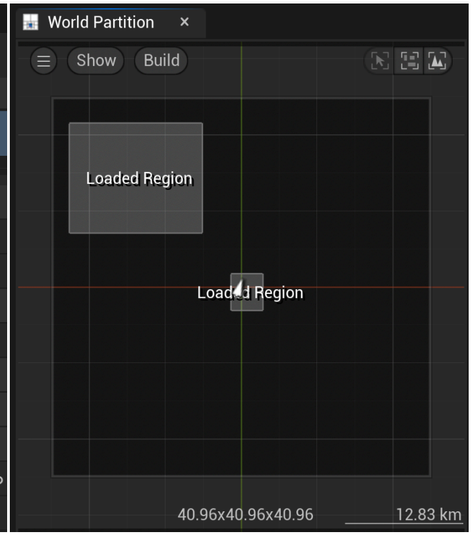

Data Layers

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- Actors may be assigned to zero or more data layers
- Filtering conditions by default form an OR operation on the highest streaming state
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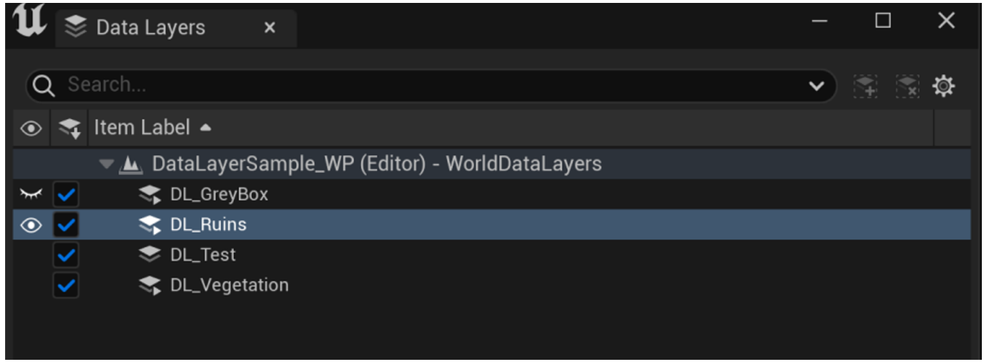

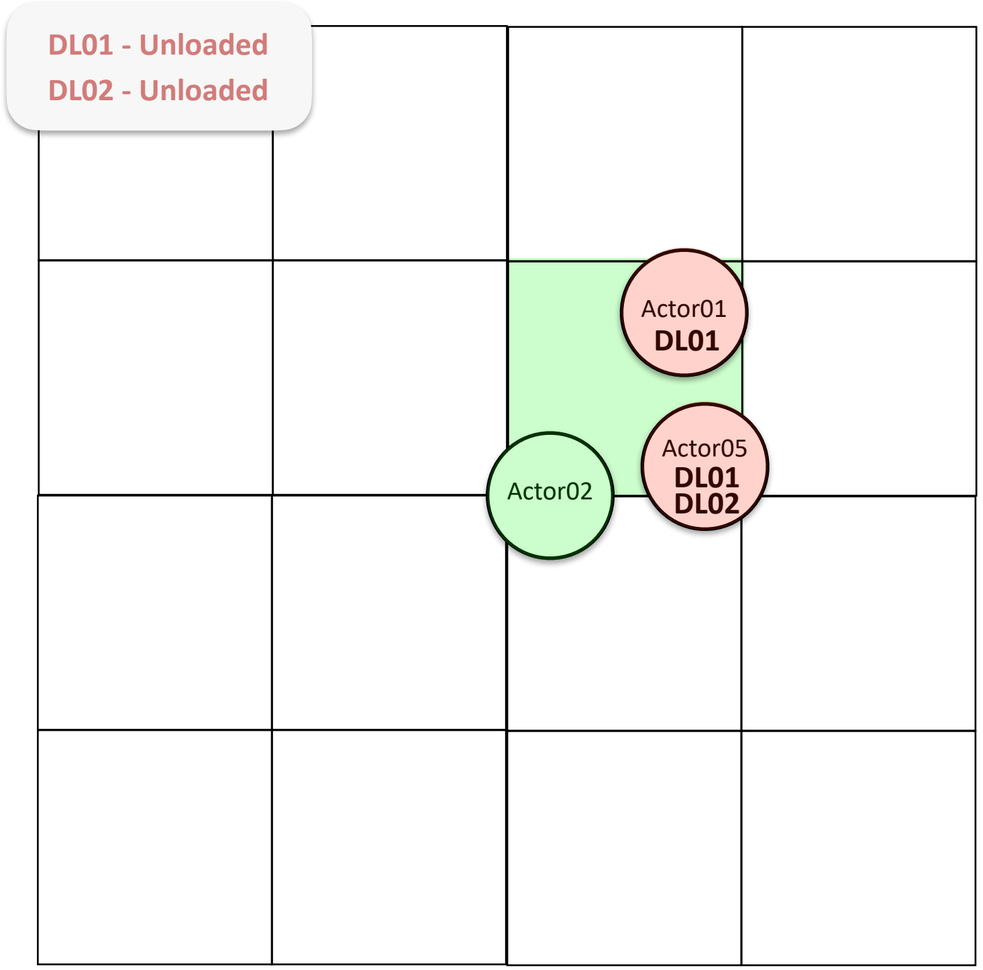

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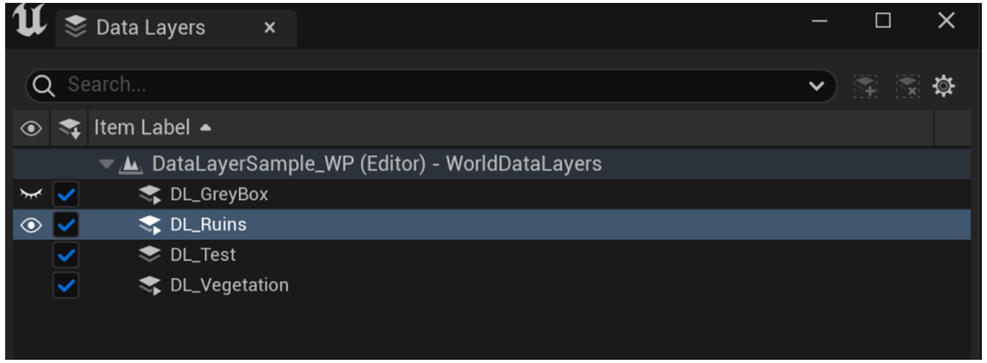

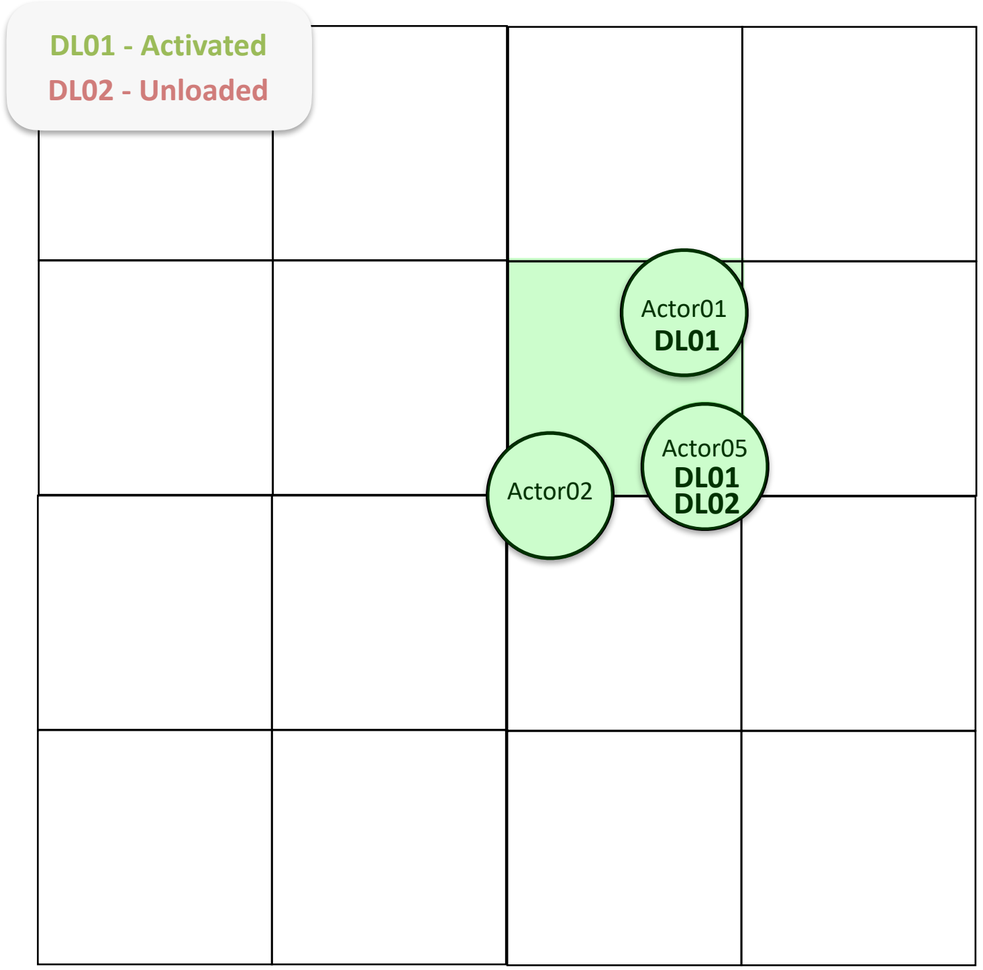

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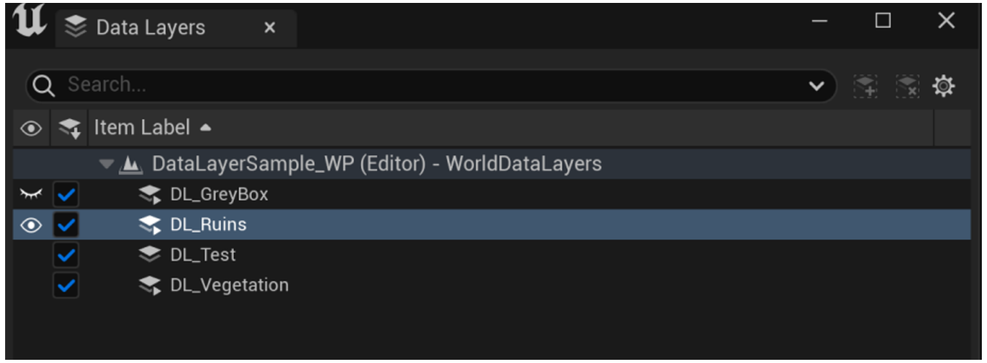

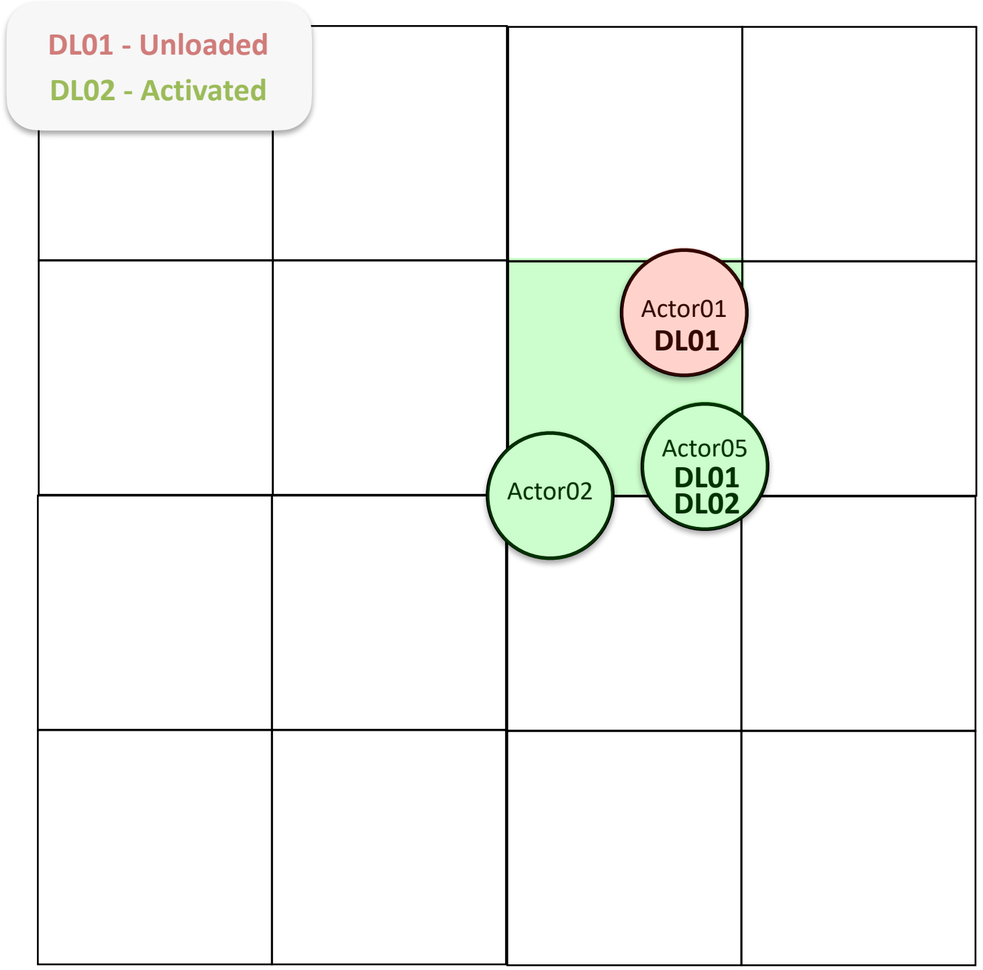

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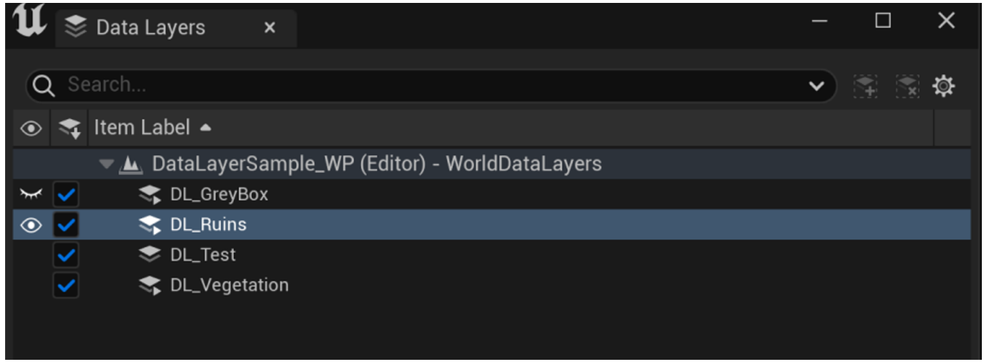

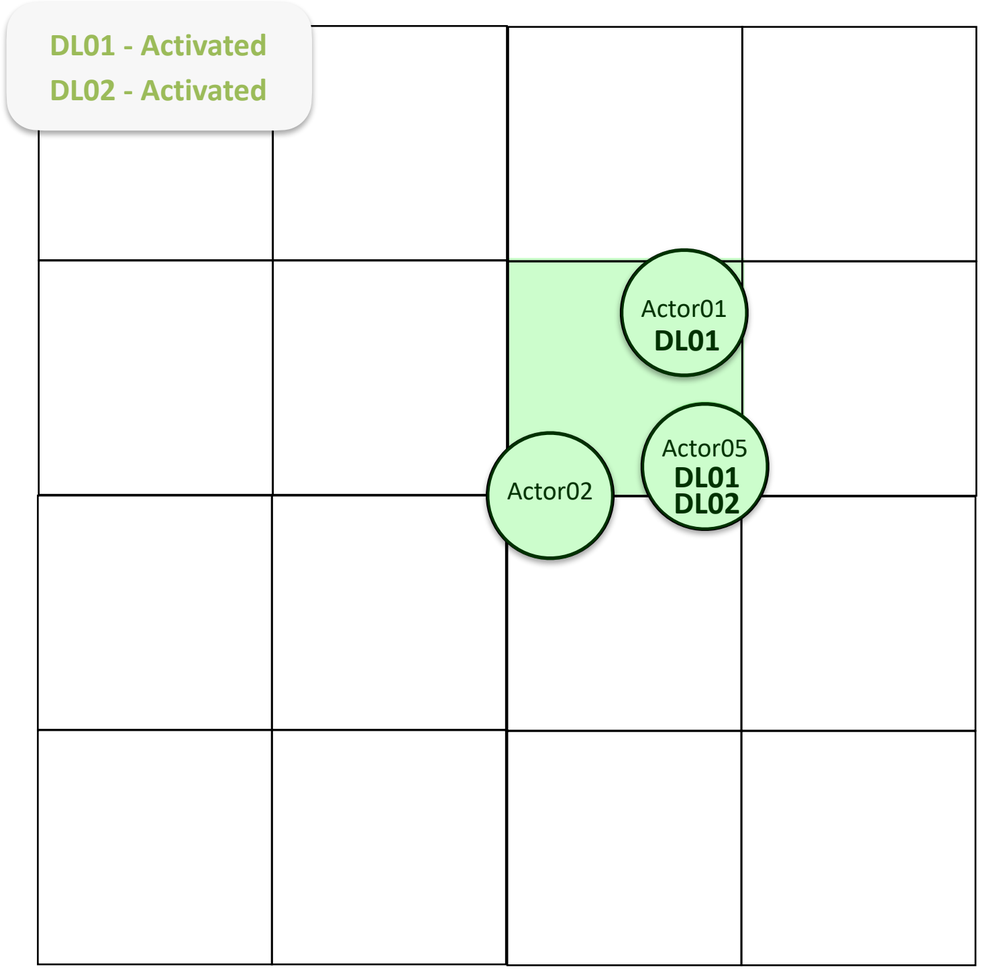

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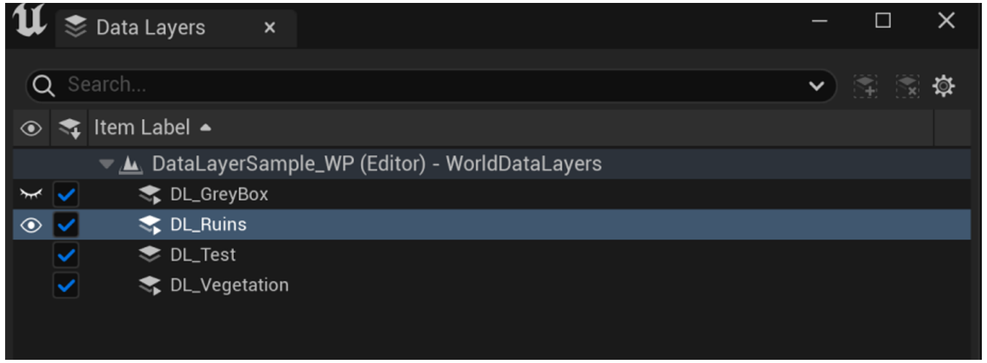

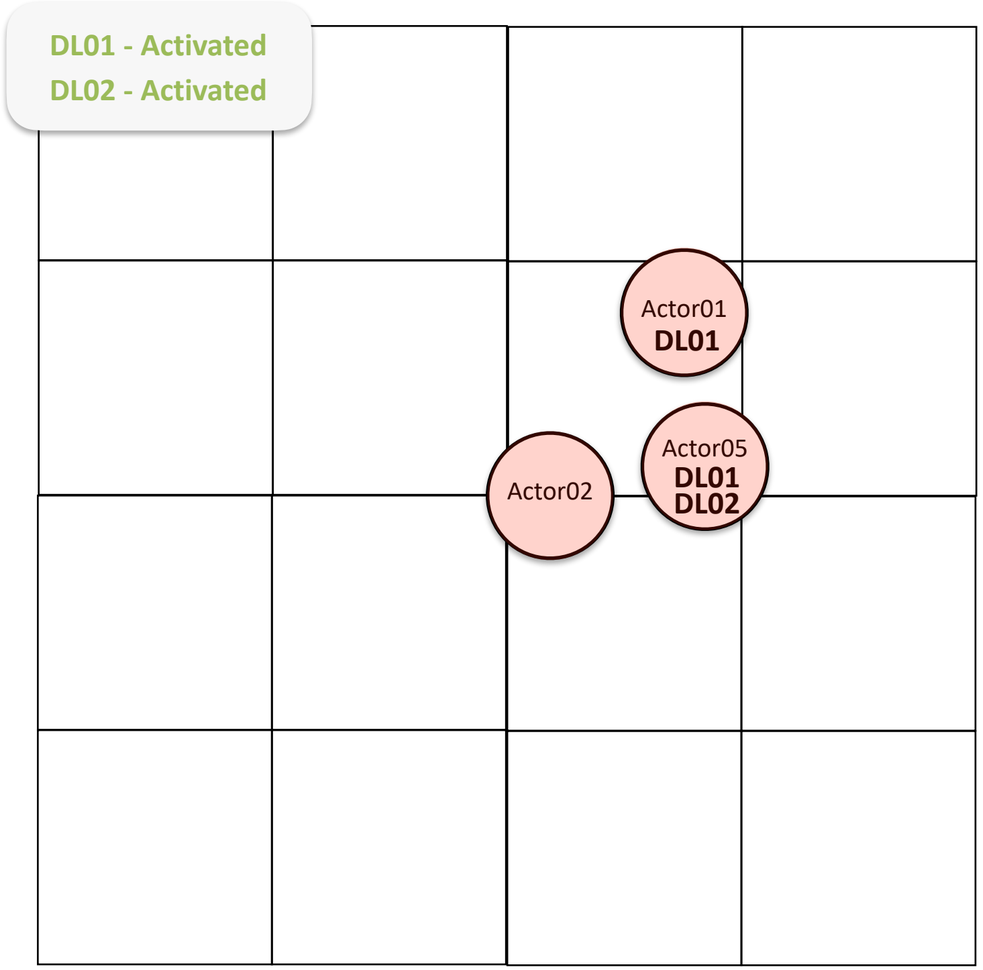

Data Layers & Streaming Generation

- Data Layers further expand the combinatorics of streaming generation rules

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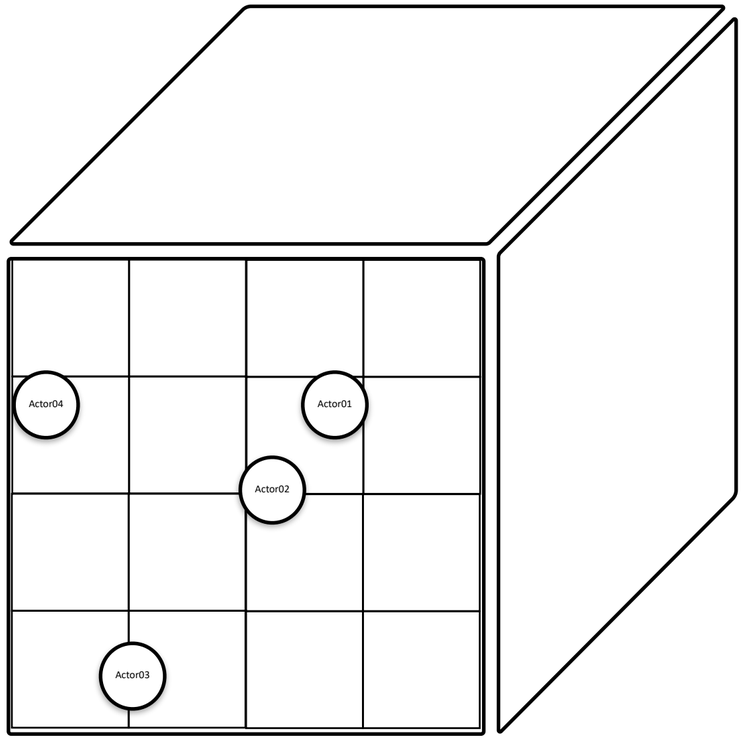

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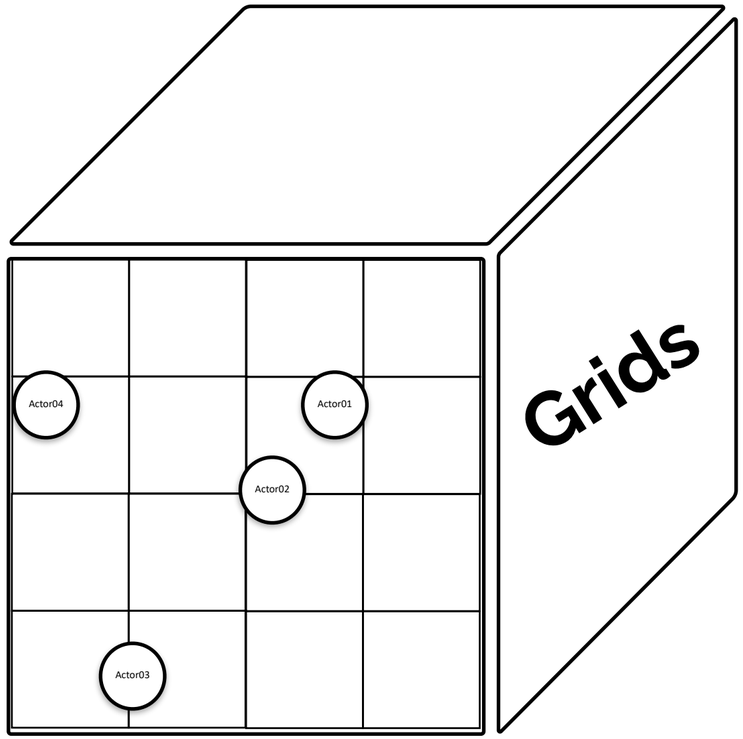

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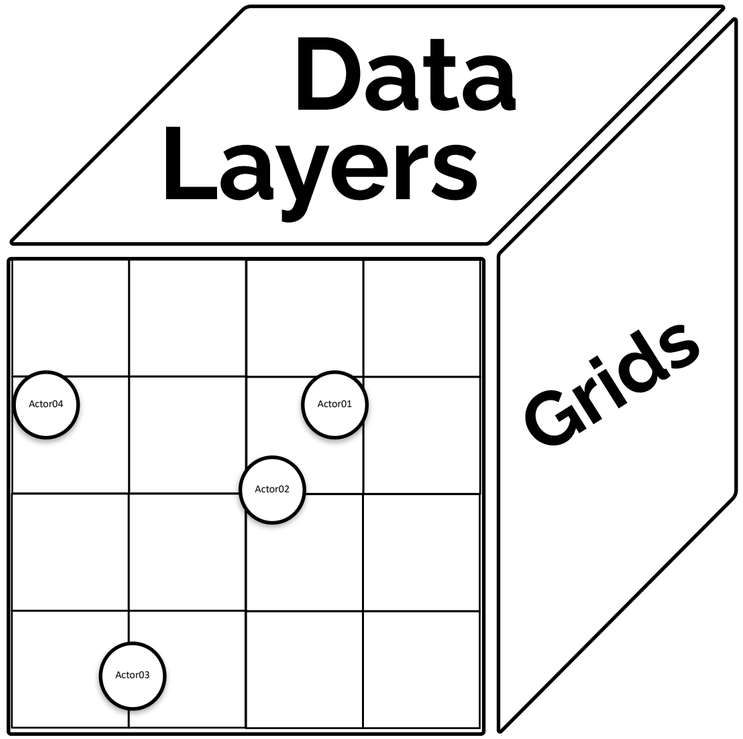

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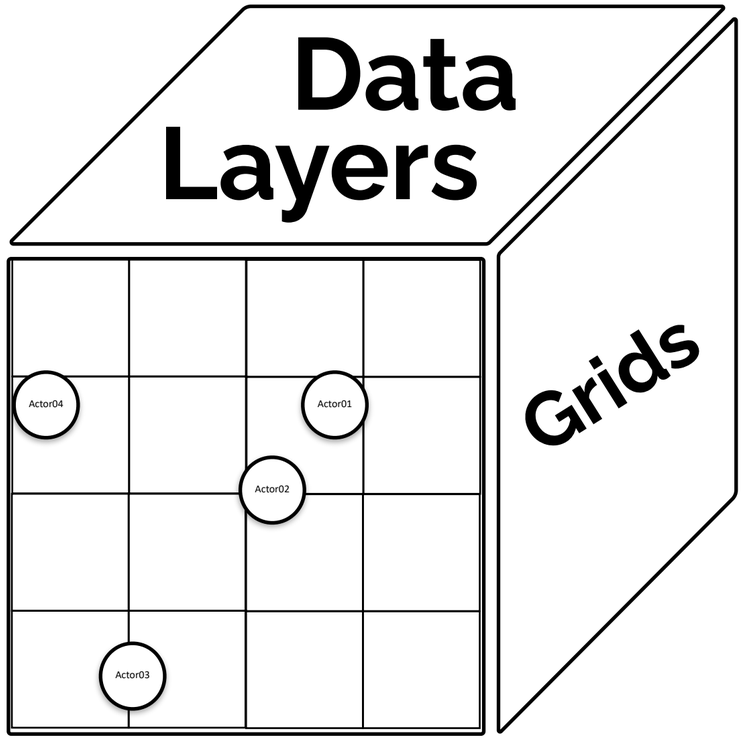

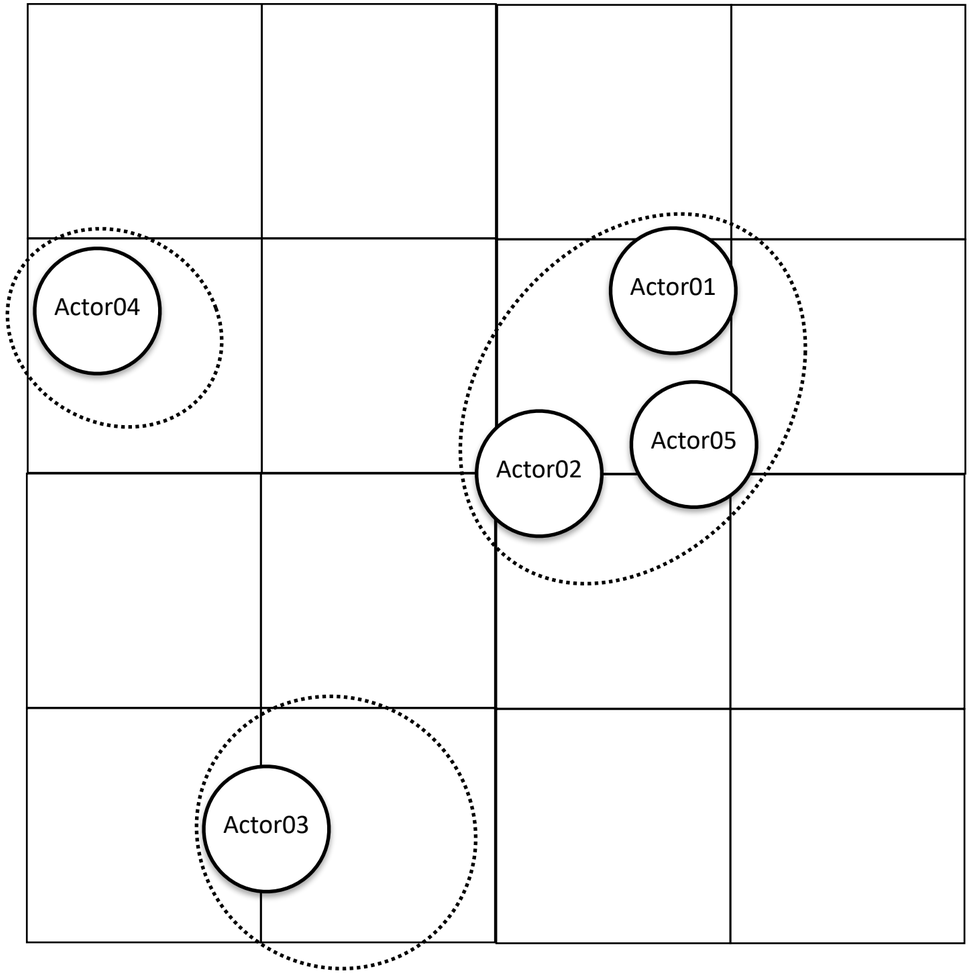

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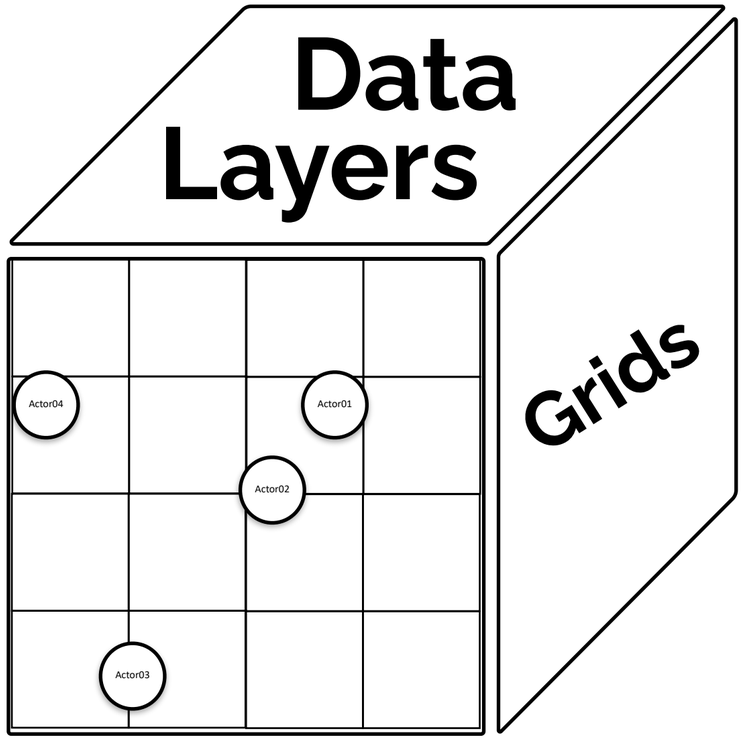

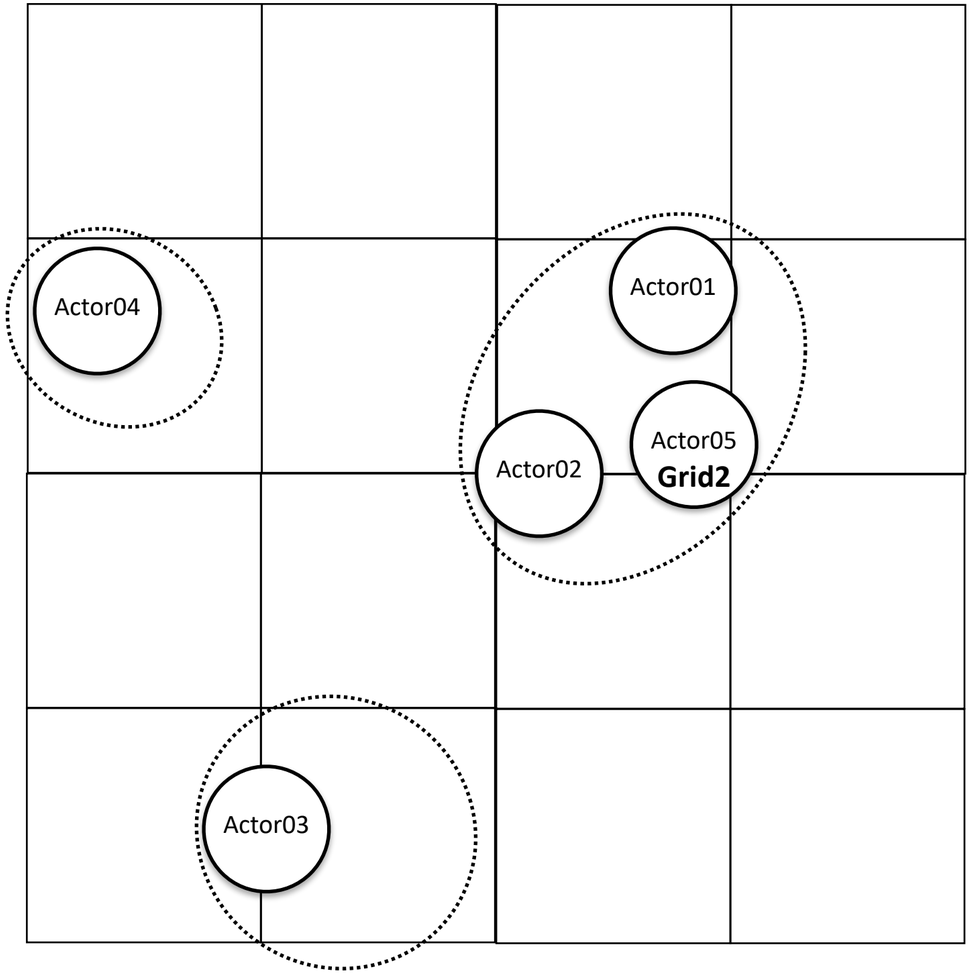

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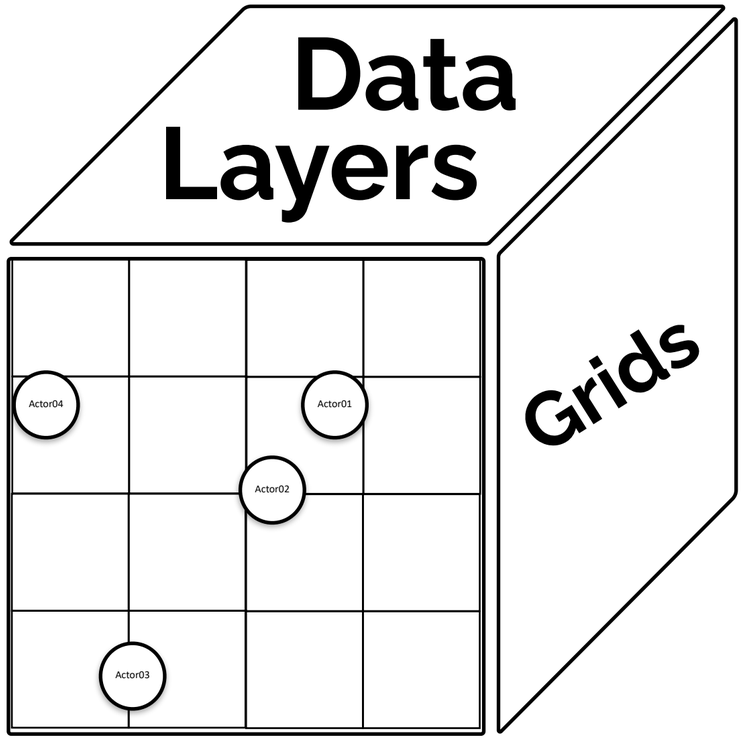

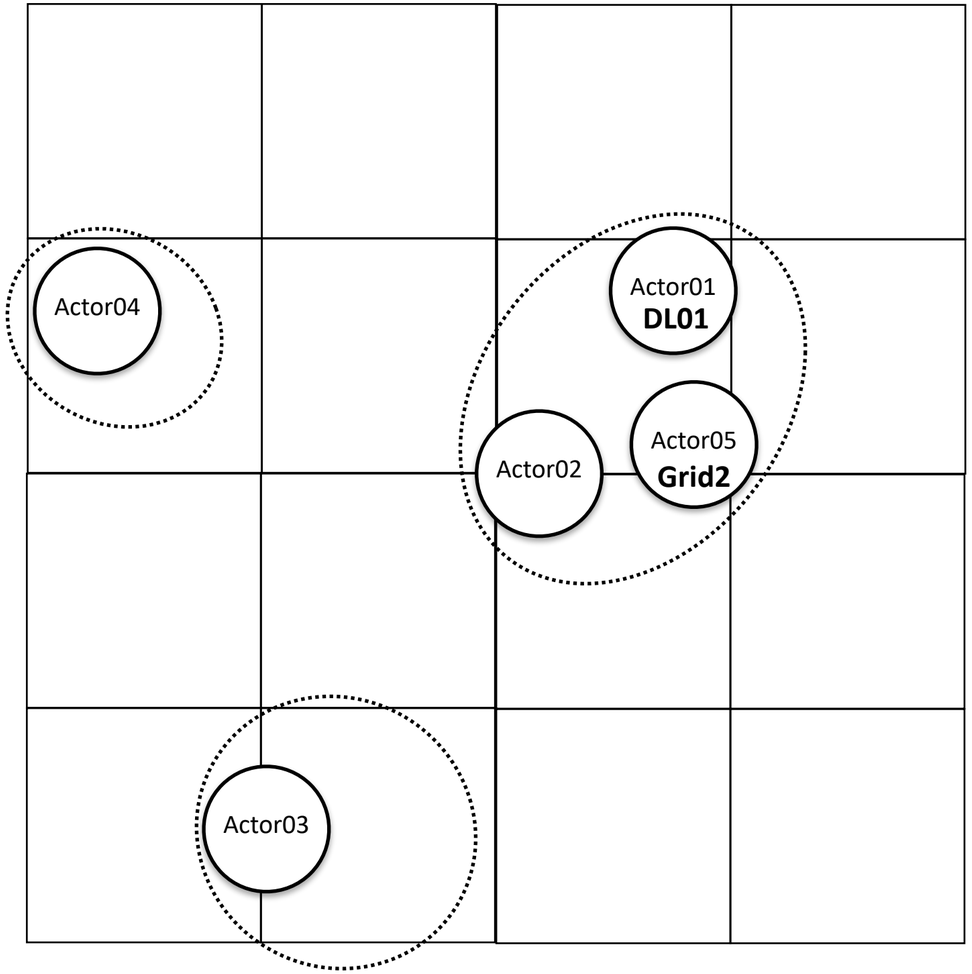

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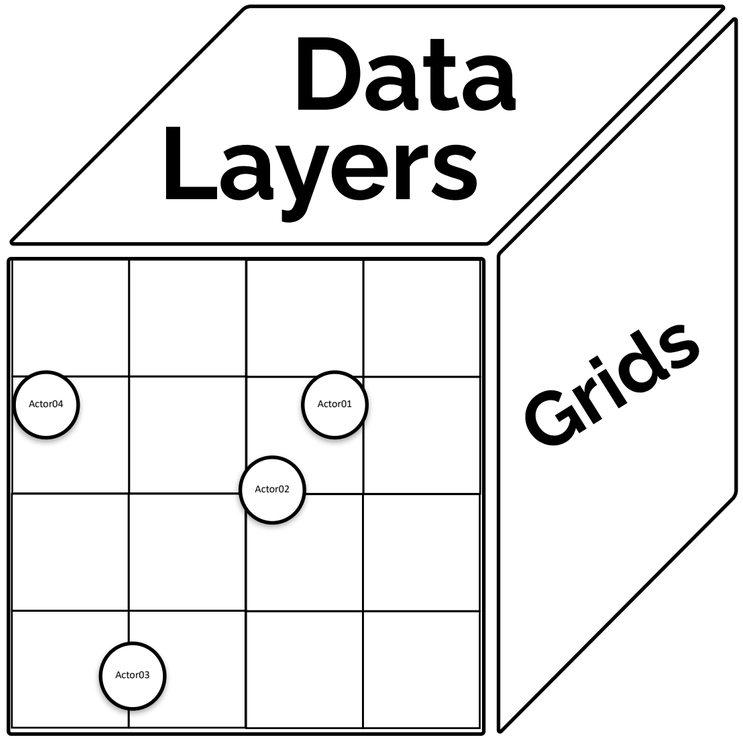

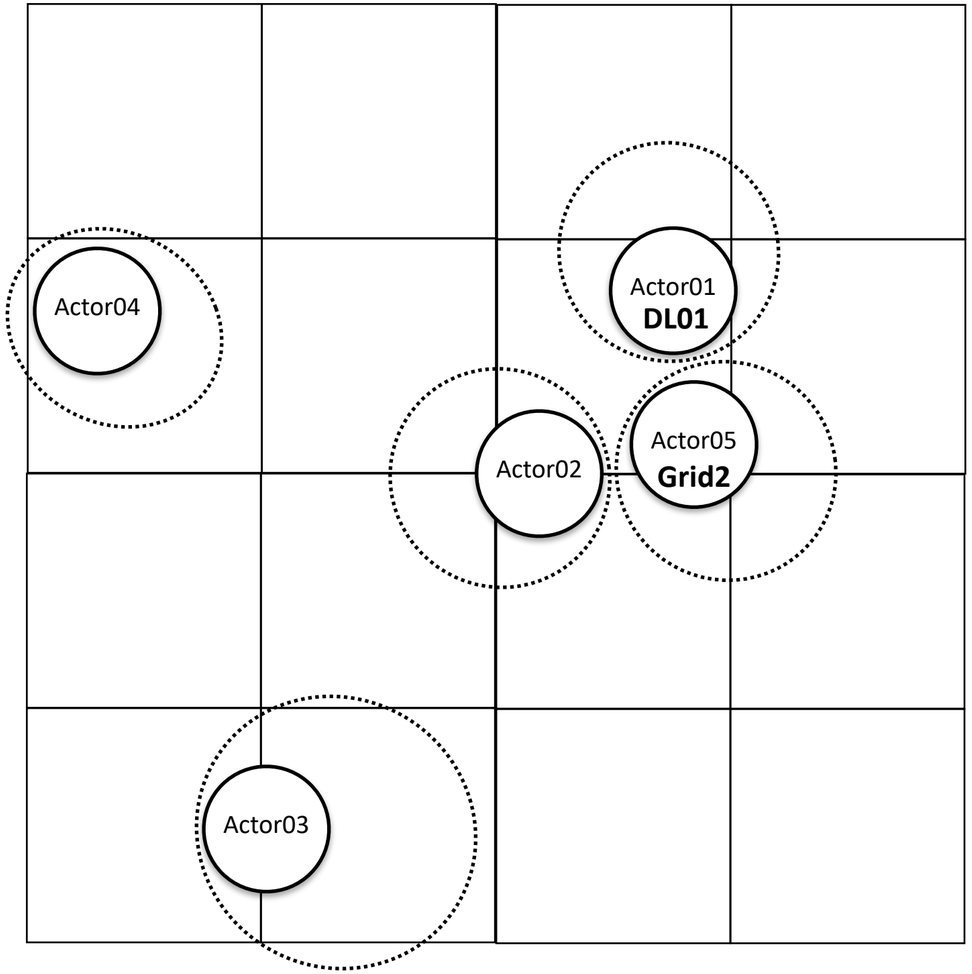

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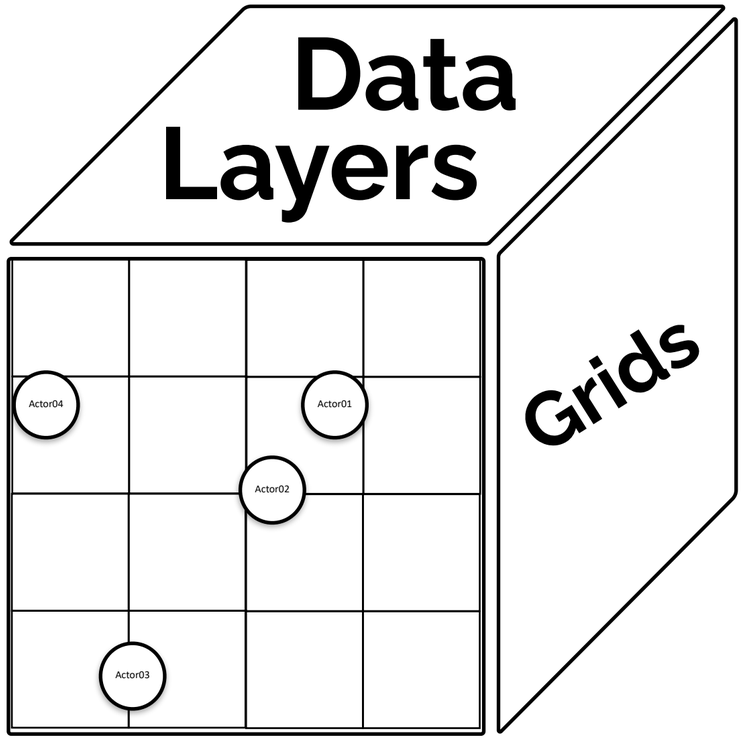
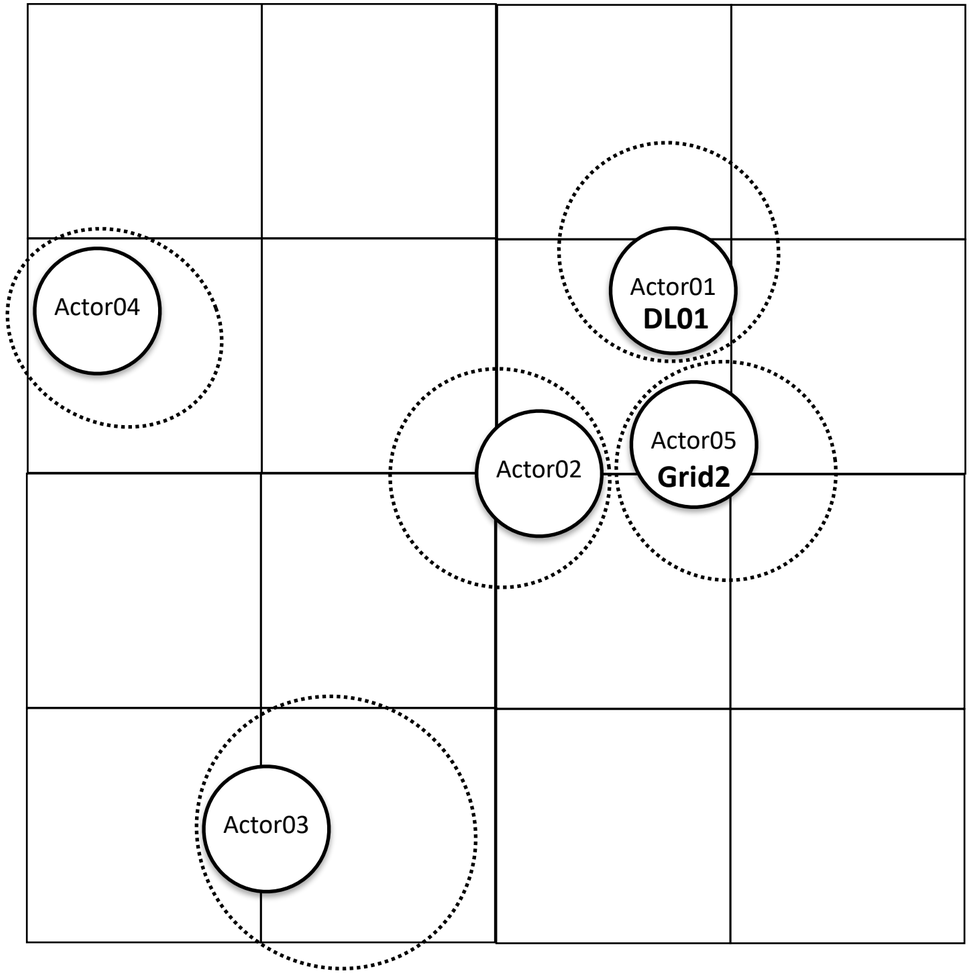


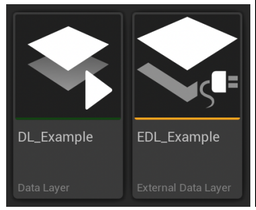
`streaming levels = cells * grids * data layers`

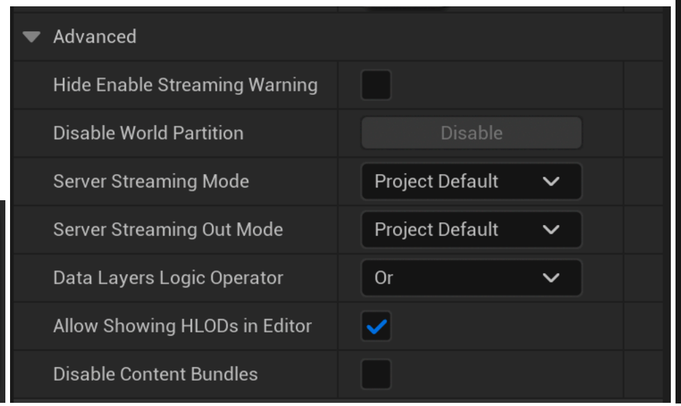
(for each unique combination used by actors)

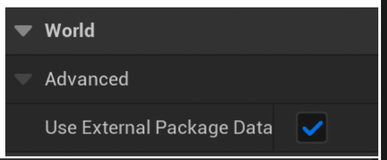


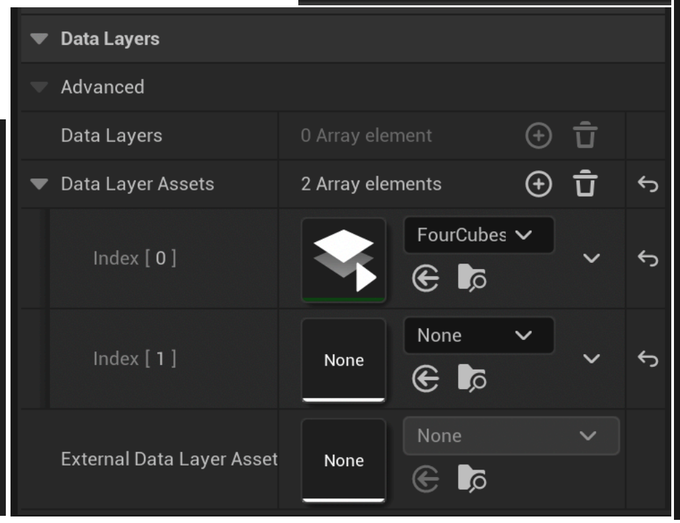
Configuring Data Layers

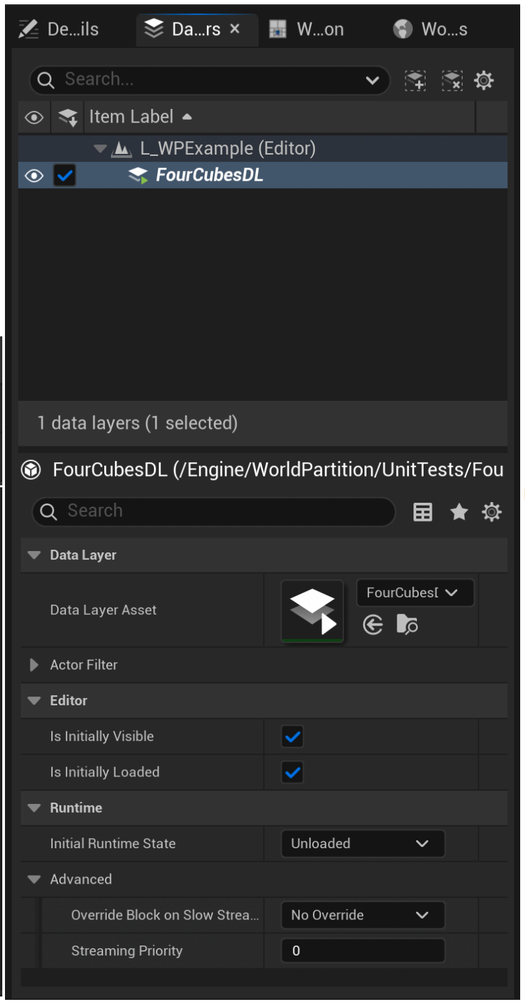
- World Partition levels automatically spawn **AWorldDataLayers** actor
  - This owns all data layer configurations for the persistent level
- Data Layers are actually configured via the Data Layer Outliner
  - Tip: enable **bUseExternalPackageData** to reduce checkout contention
- Data Layer Assets can be set to runtime or editor
- Data Layer Instances be placed in a hierarchy, where relationships reduce to an effective “min” streaming state
- Can be reconfigured from OR to AND
- External layers for game feature plugins







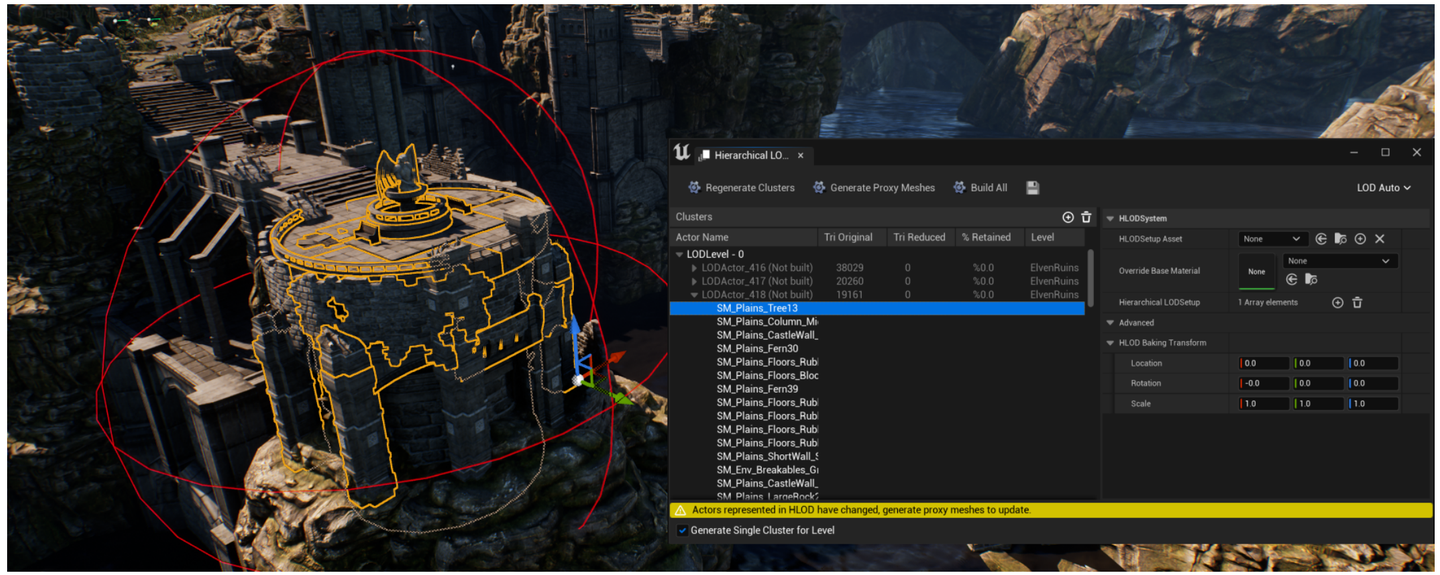




Hierarchical Level of Detail (HLODs)

- Tool to generate “proxy meshes” that can be swapped out at different LOD levels
- Can load in HLODs as distant grid cells are streamed out, providing lower cost distant geometry

- Supports instanced, merged, simplified, and approximated static mesh transformations



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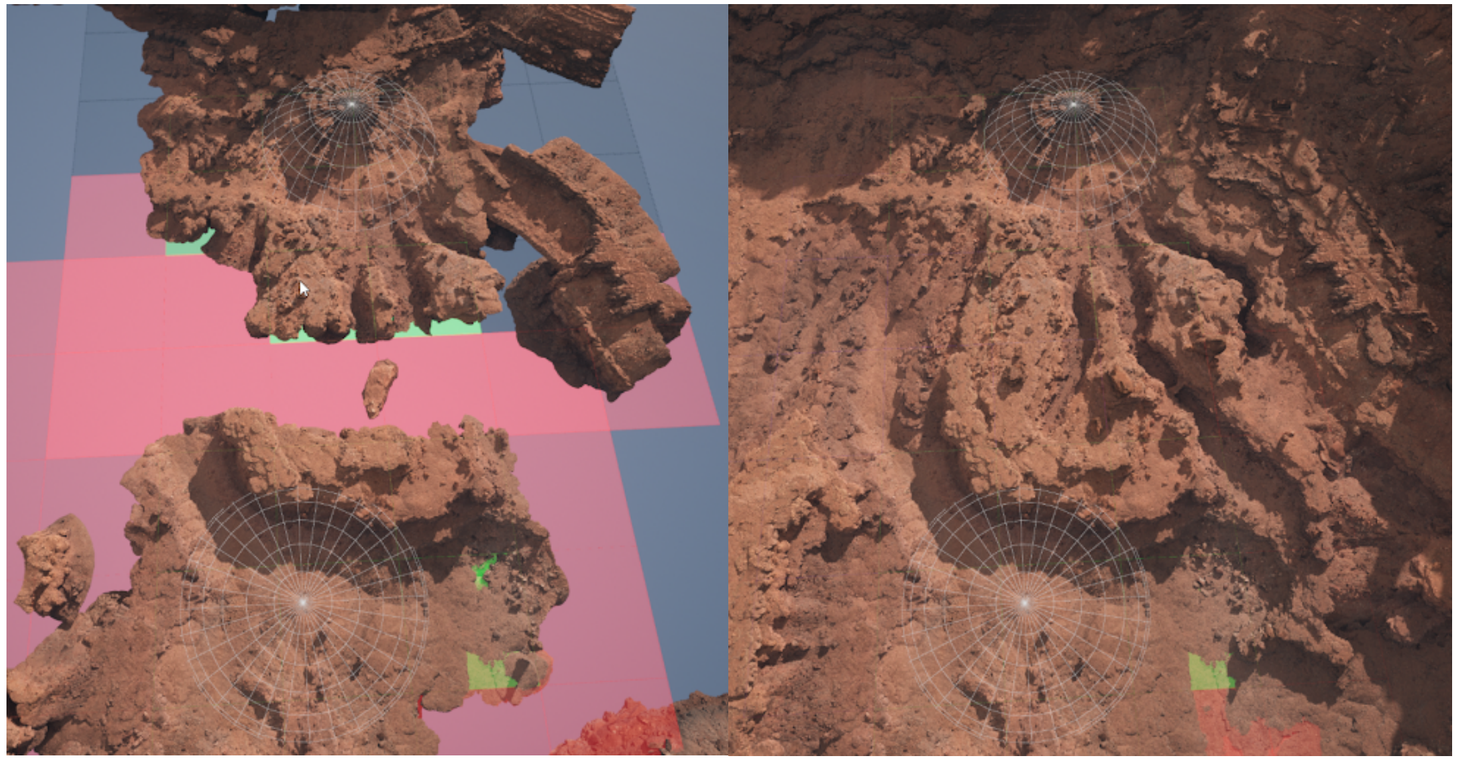

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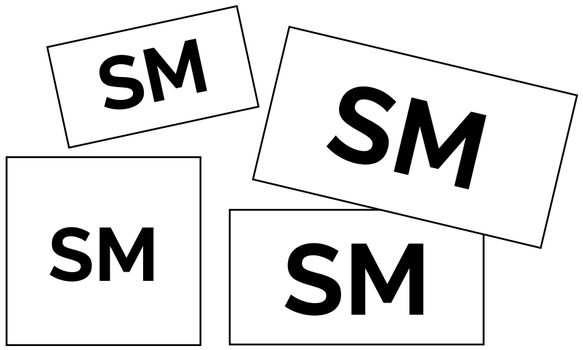

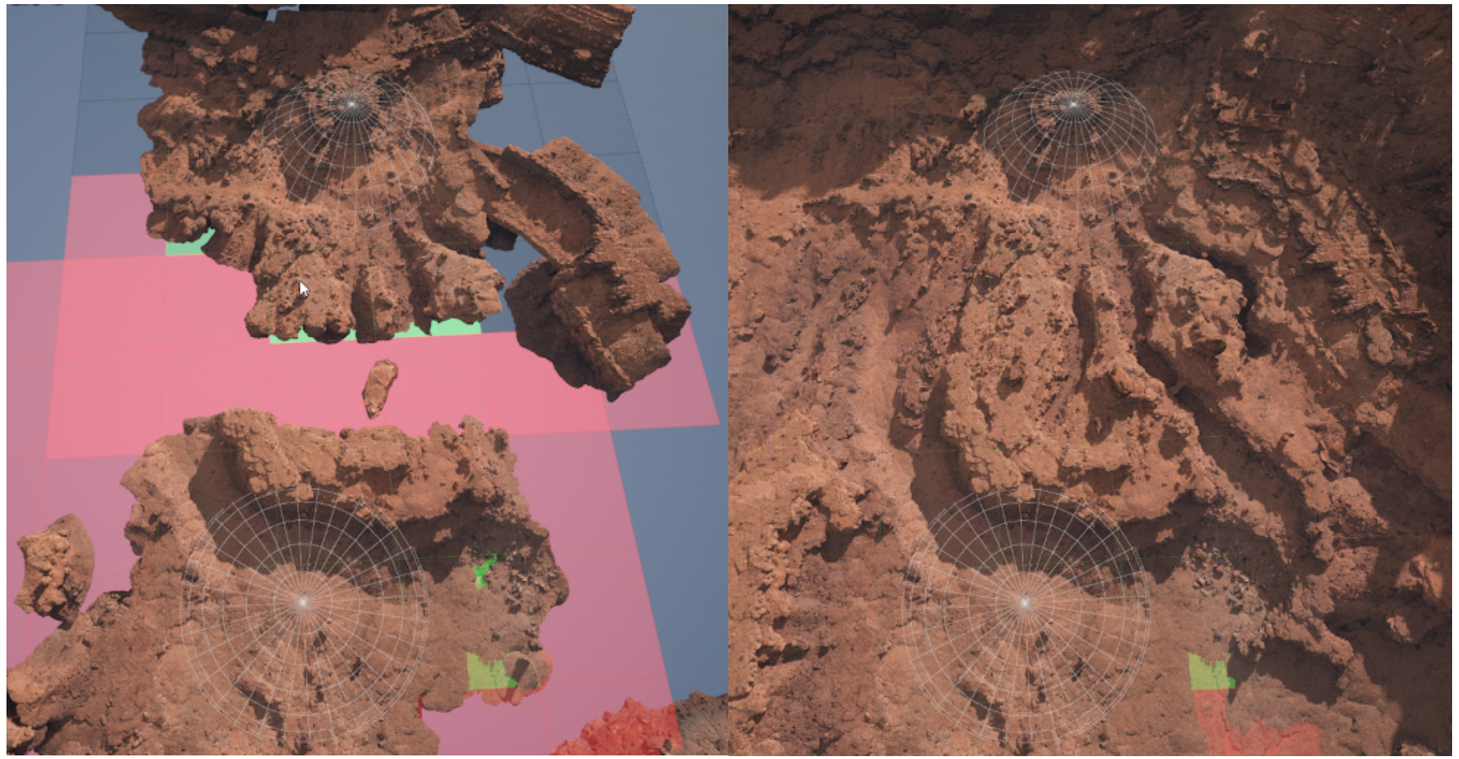

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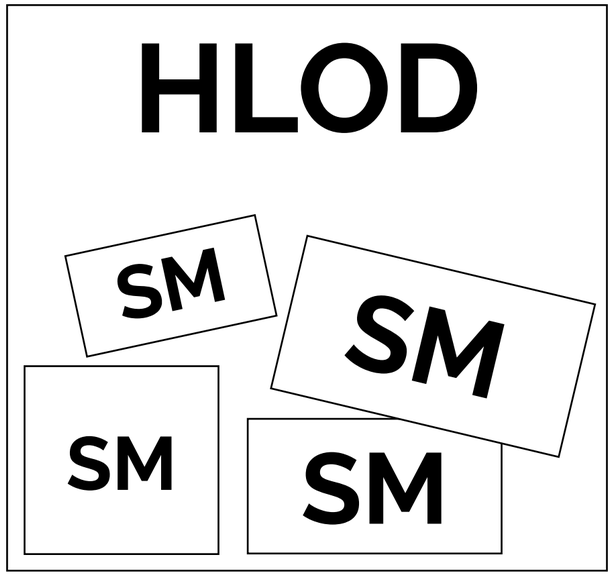

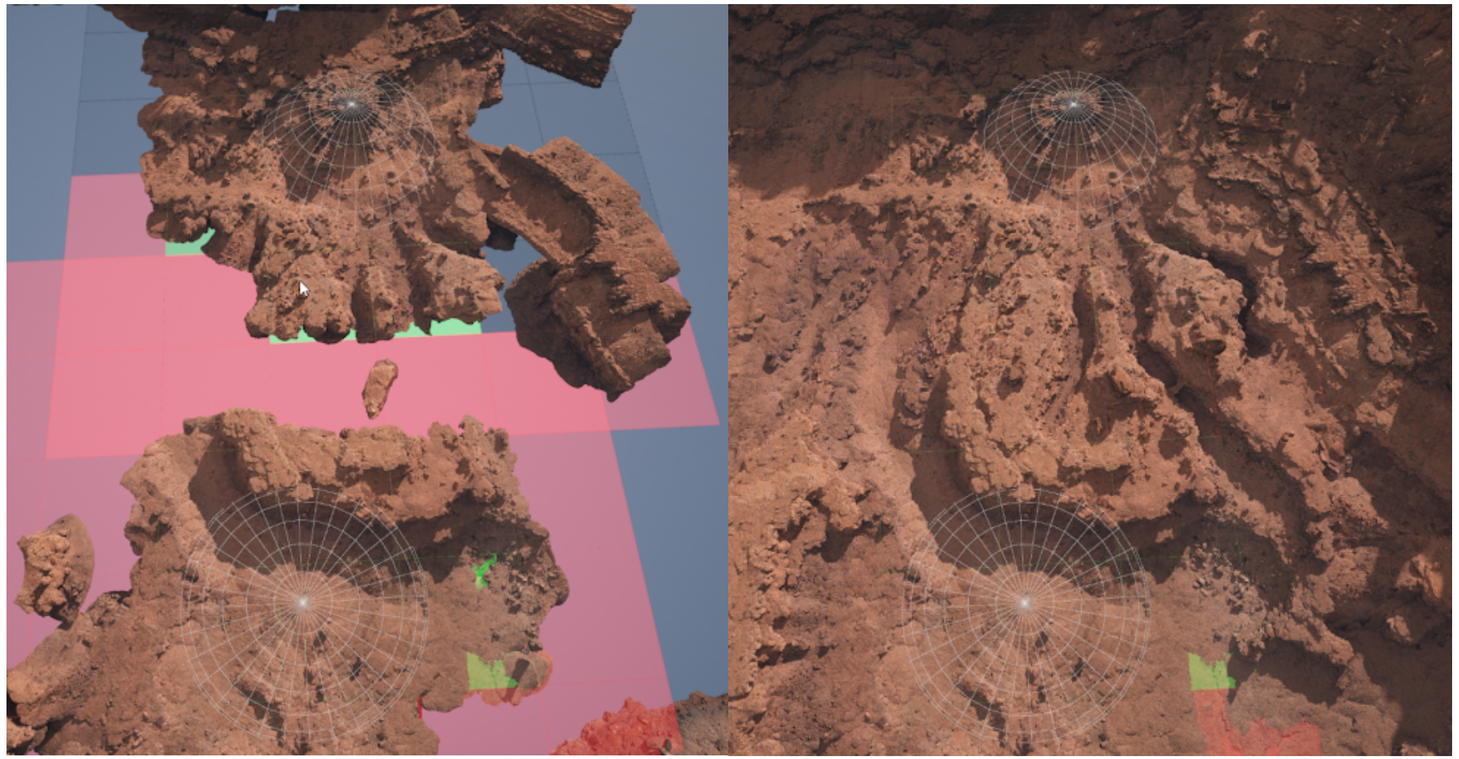

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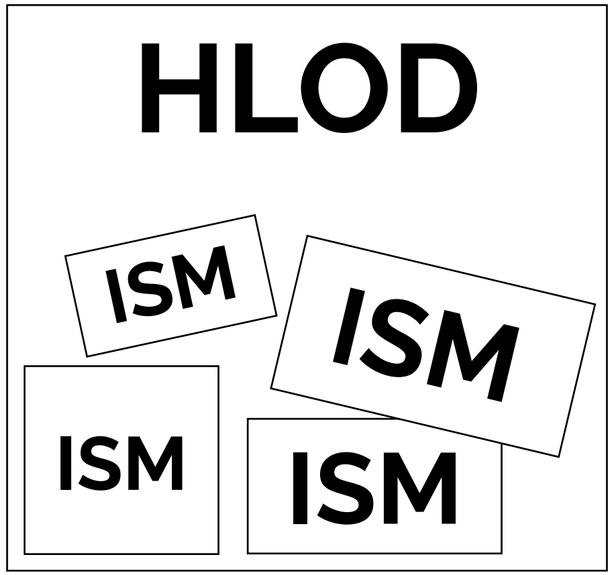

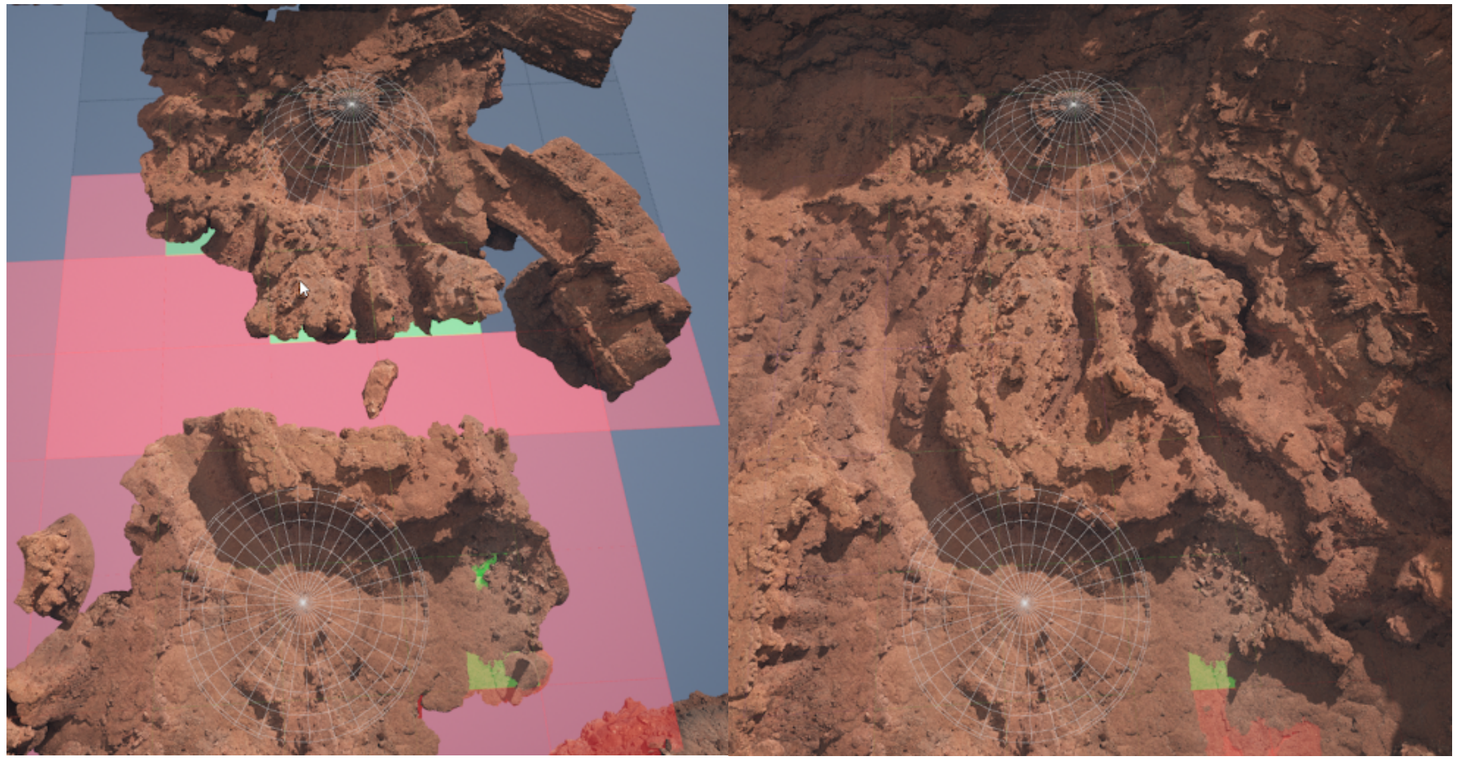

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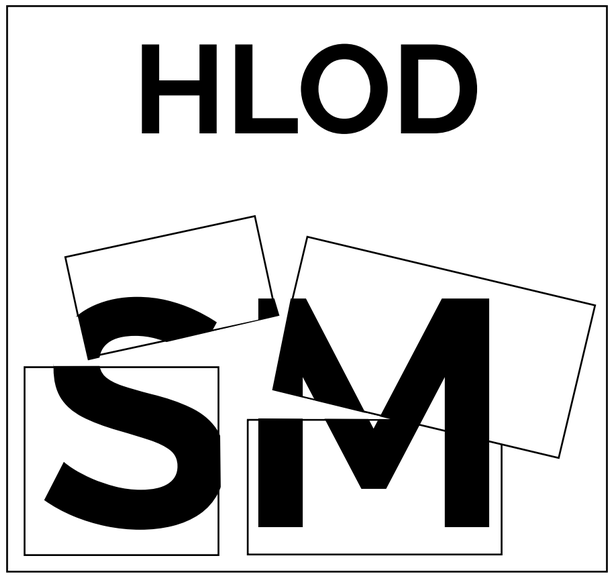

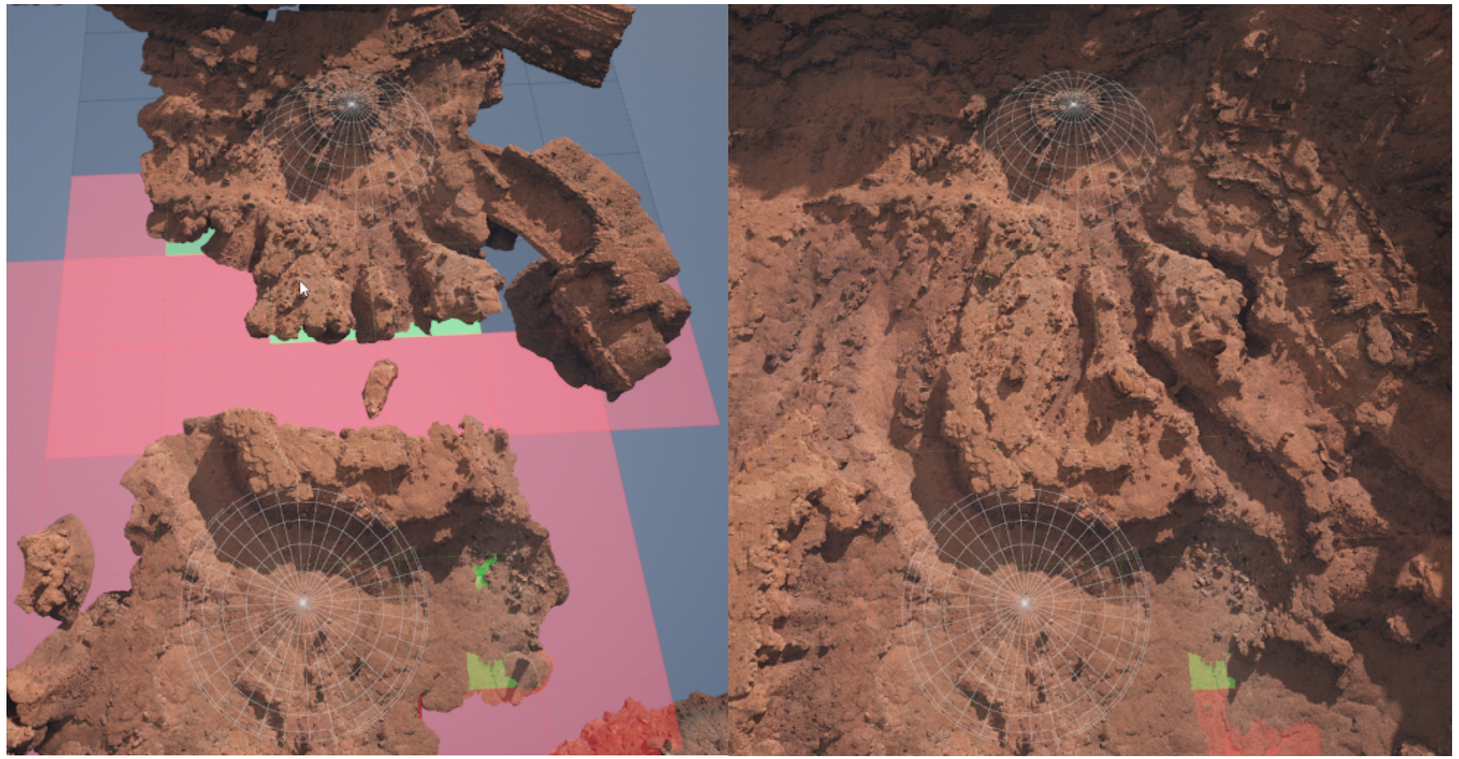

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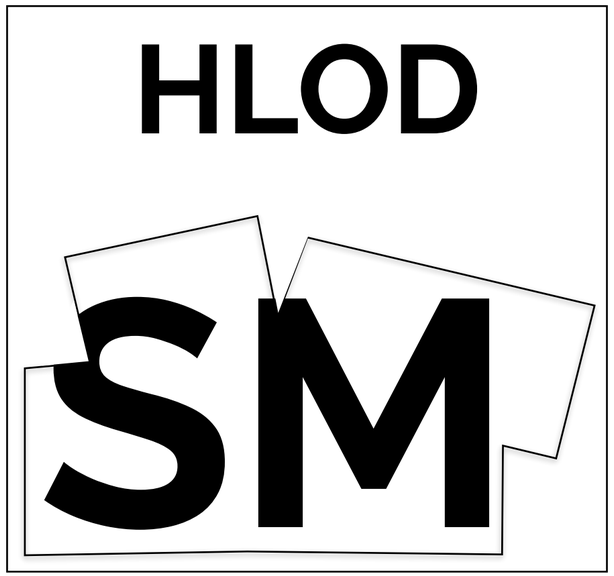

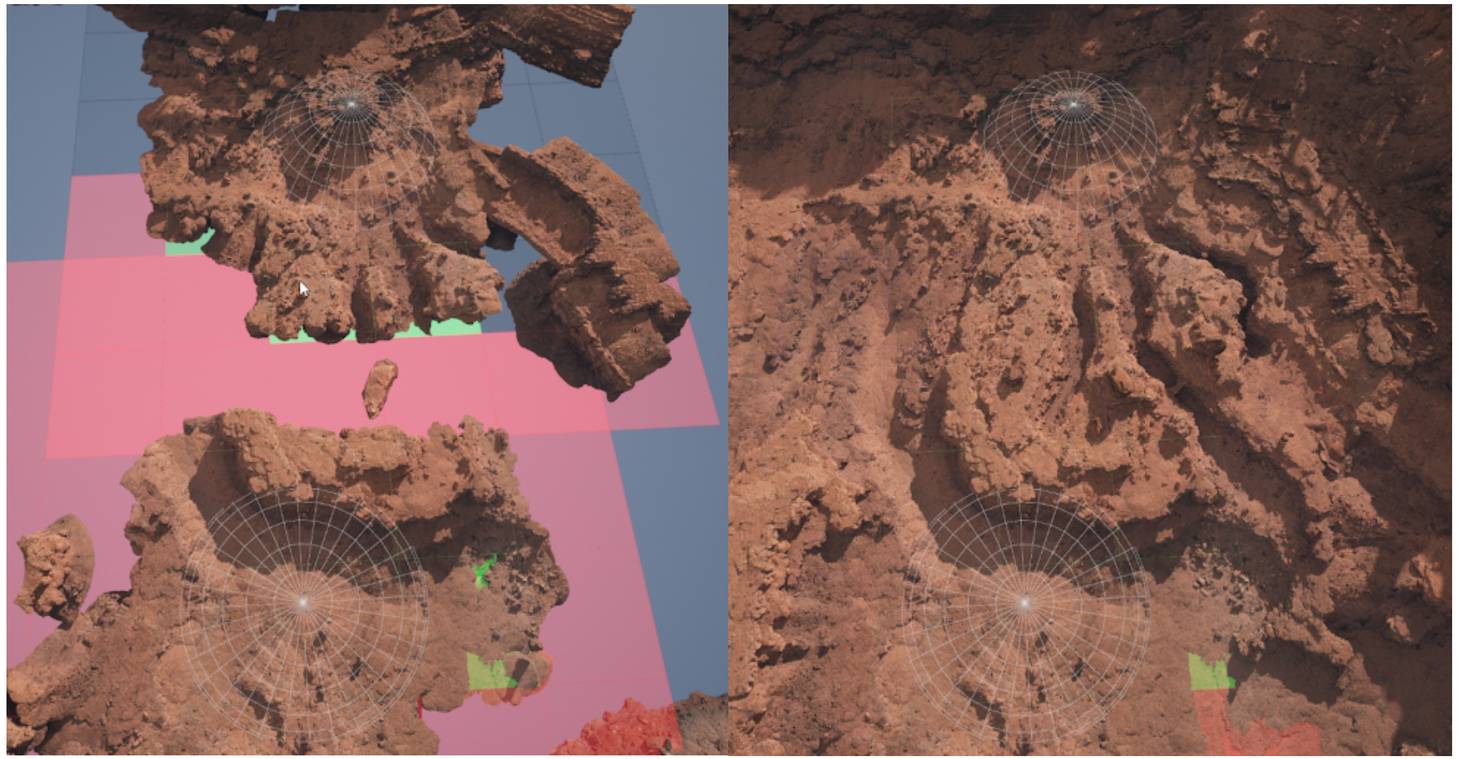

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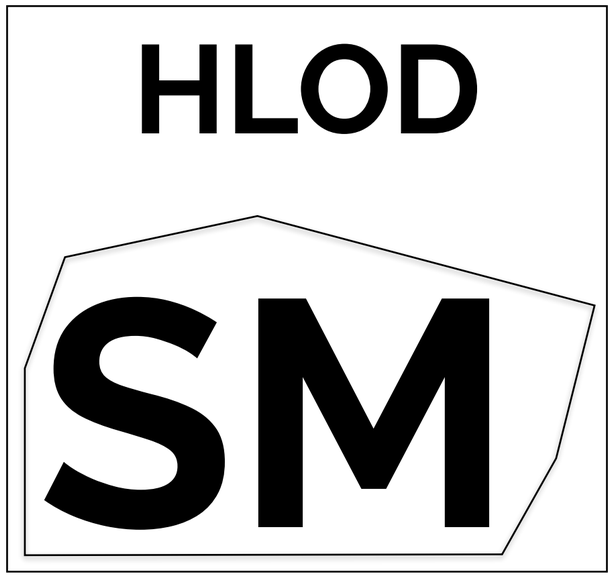

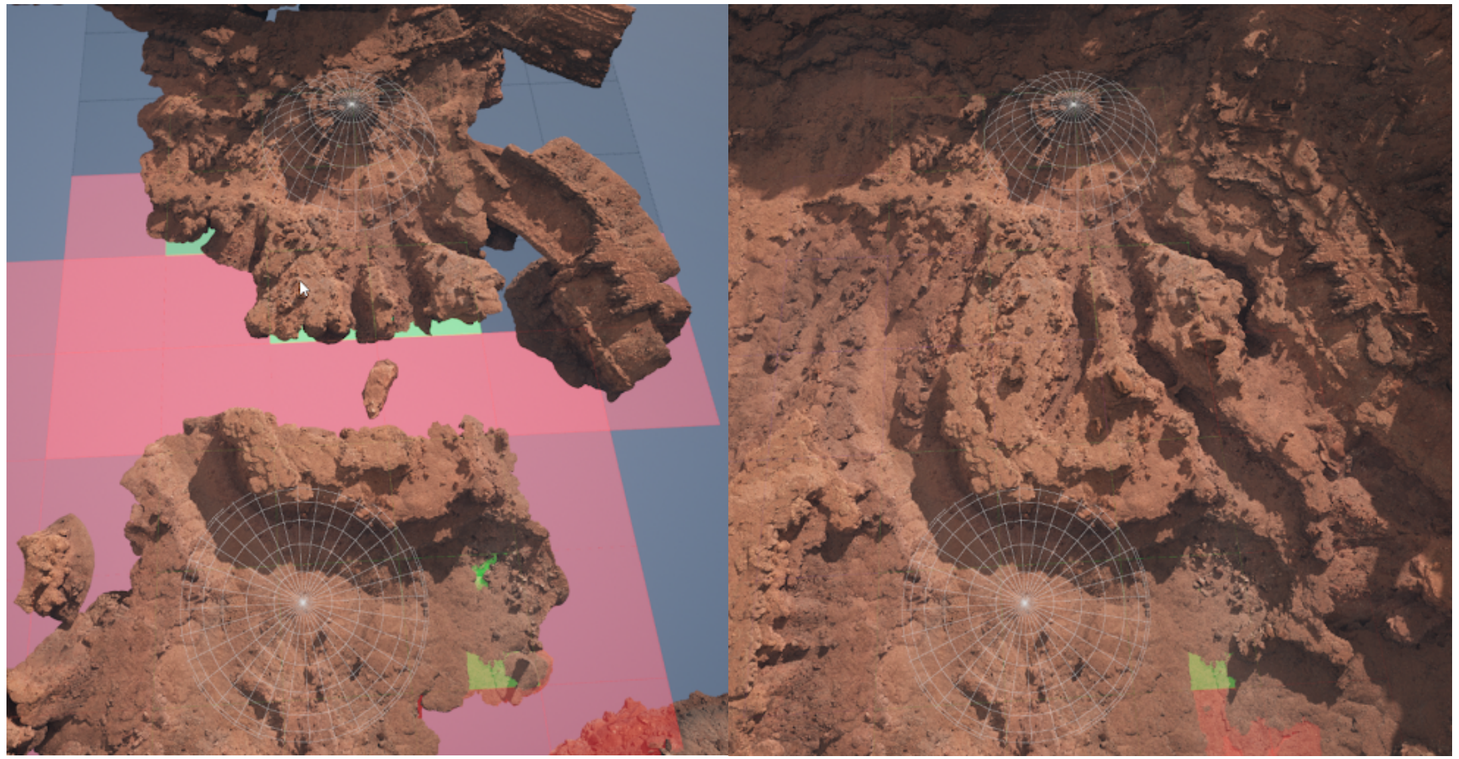

Level Instances

- Provide Unreal with its own version of a “prefab”
- Essentially functions as a sub-level
- Changes are propagated across all instances
- Editing can be done in-situ
- Unpacked at at PIE/Cook time
- Data layers can be assigned to level instances but will be inherited by all owned actors
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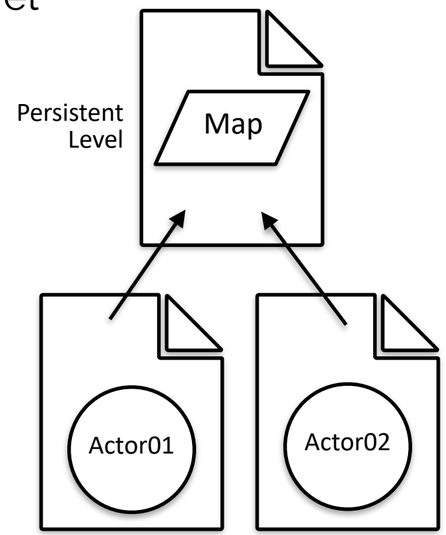

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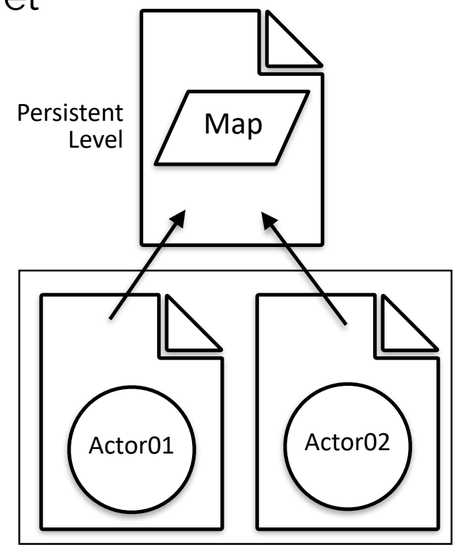

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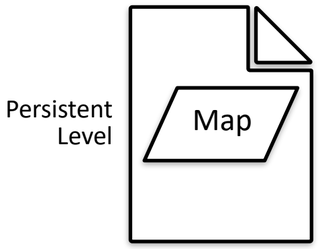

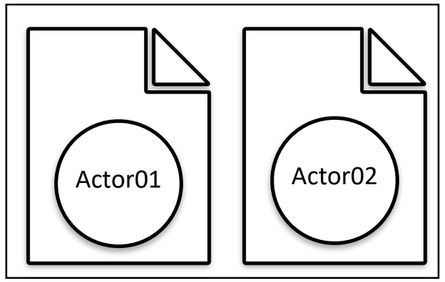

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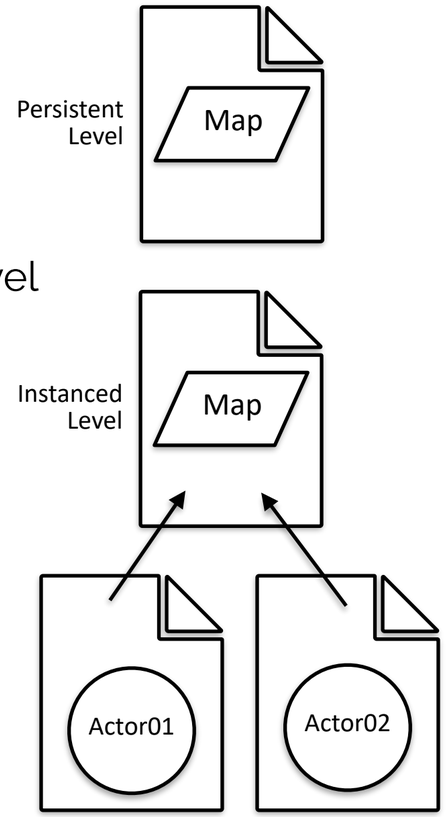

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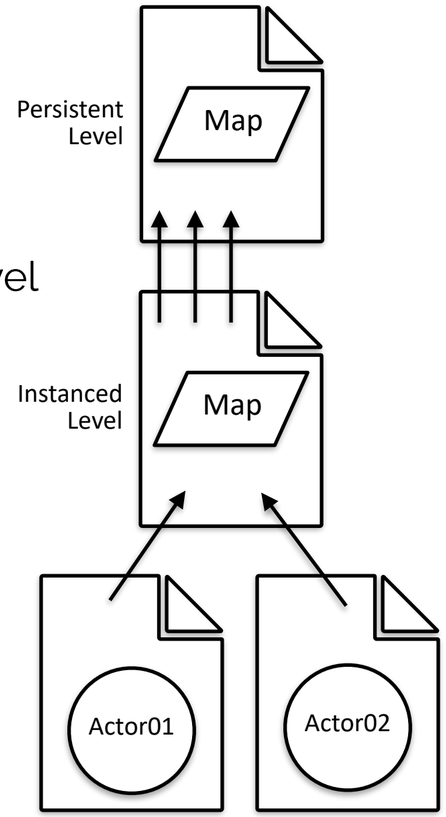
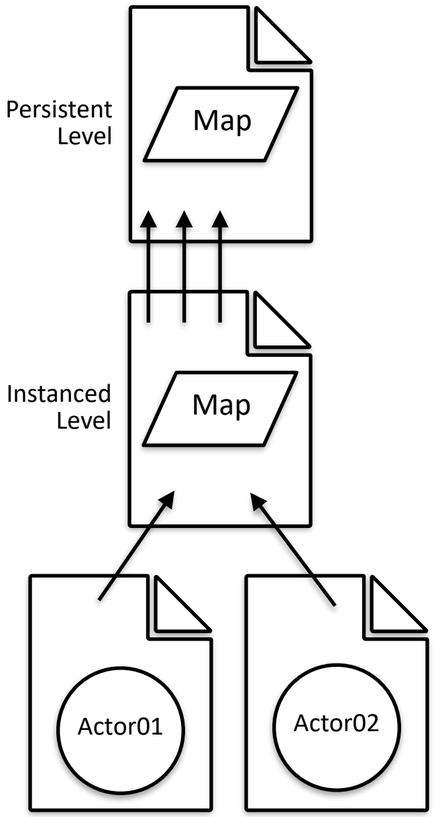
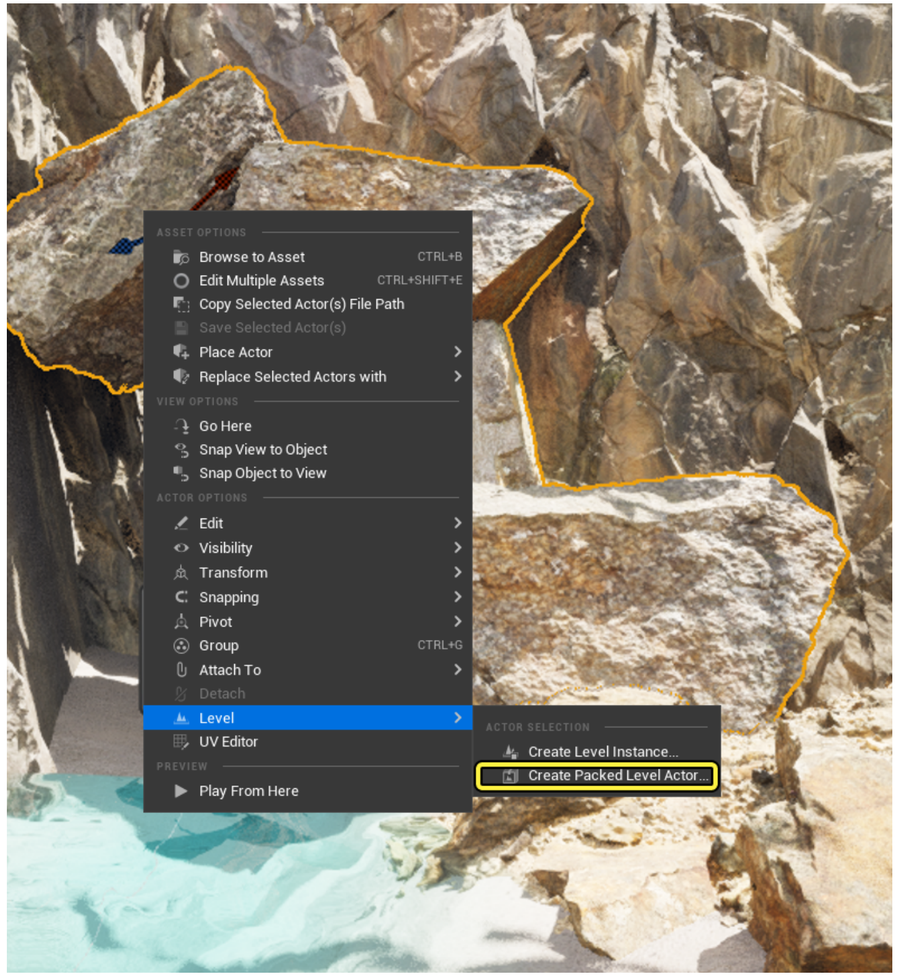


Packed Level Actors

- Discards all components that are not static meshes
- Automatically generates instanced static meshes
- Generates two files
- Avoid editing in the BP
- Be careful moving files around
- Bounds affect streaming



- These are great for large groups of smaller geometry pieces that may be repeated
- Try use instead of level instances whenever possible



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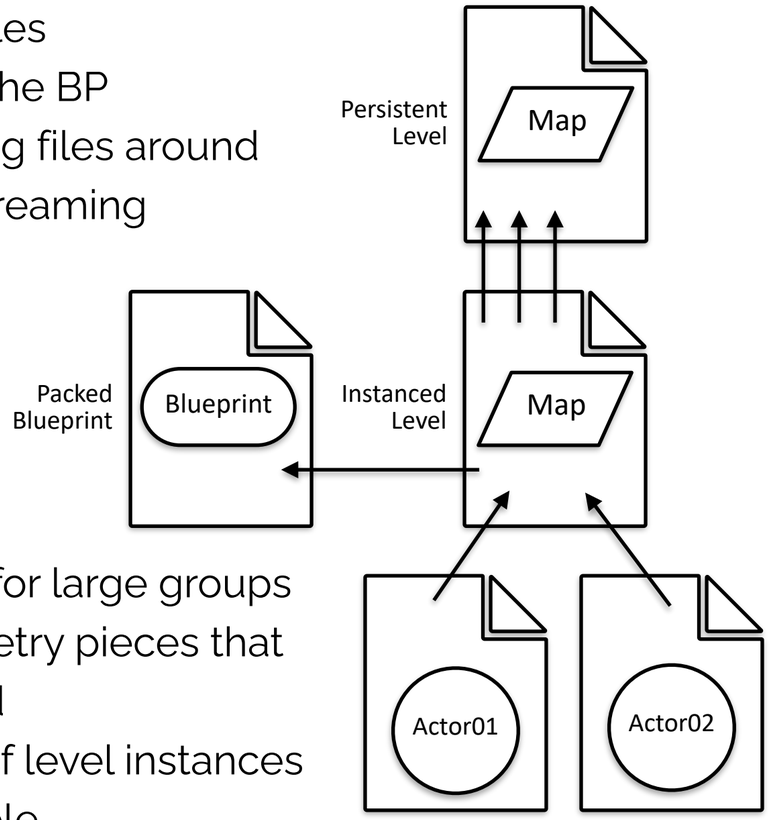

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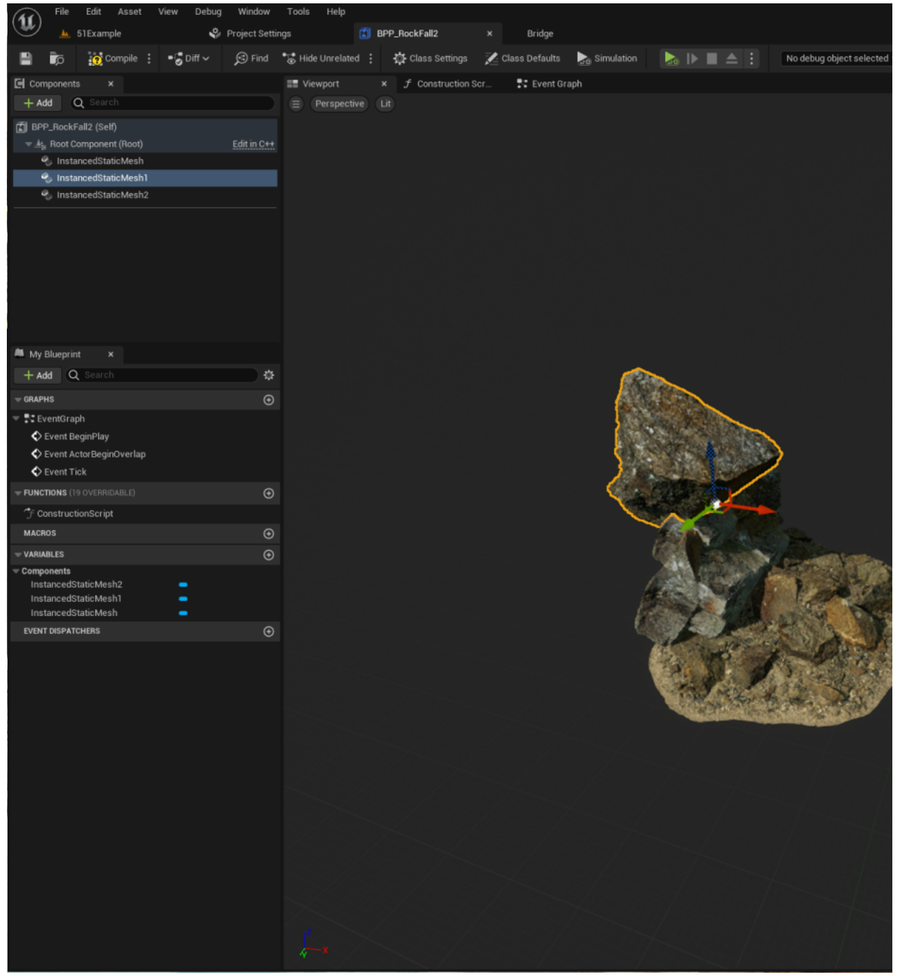

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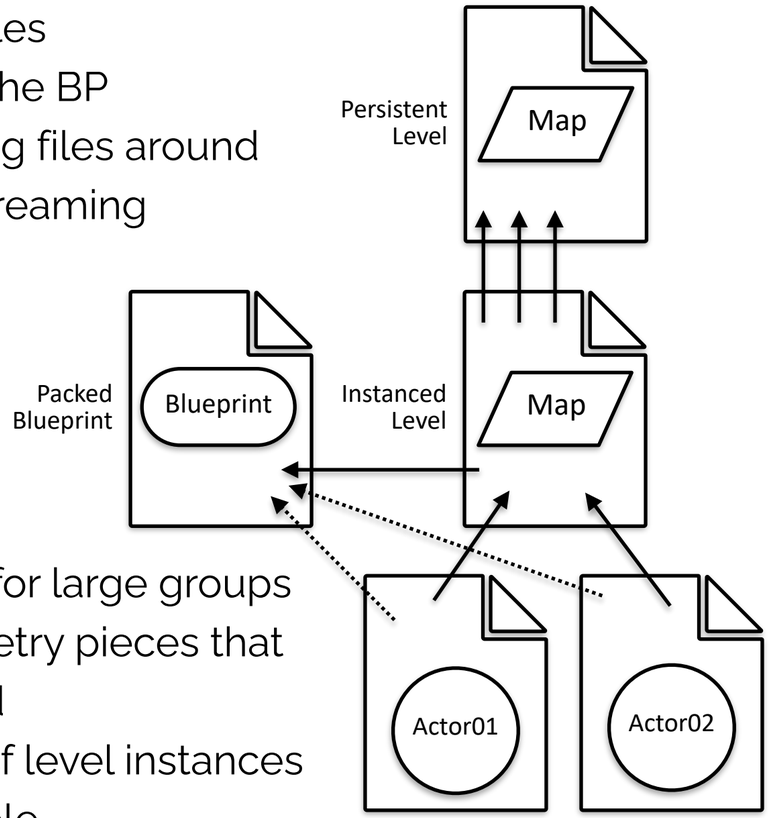

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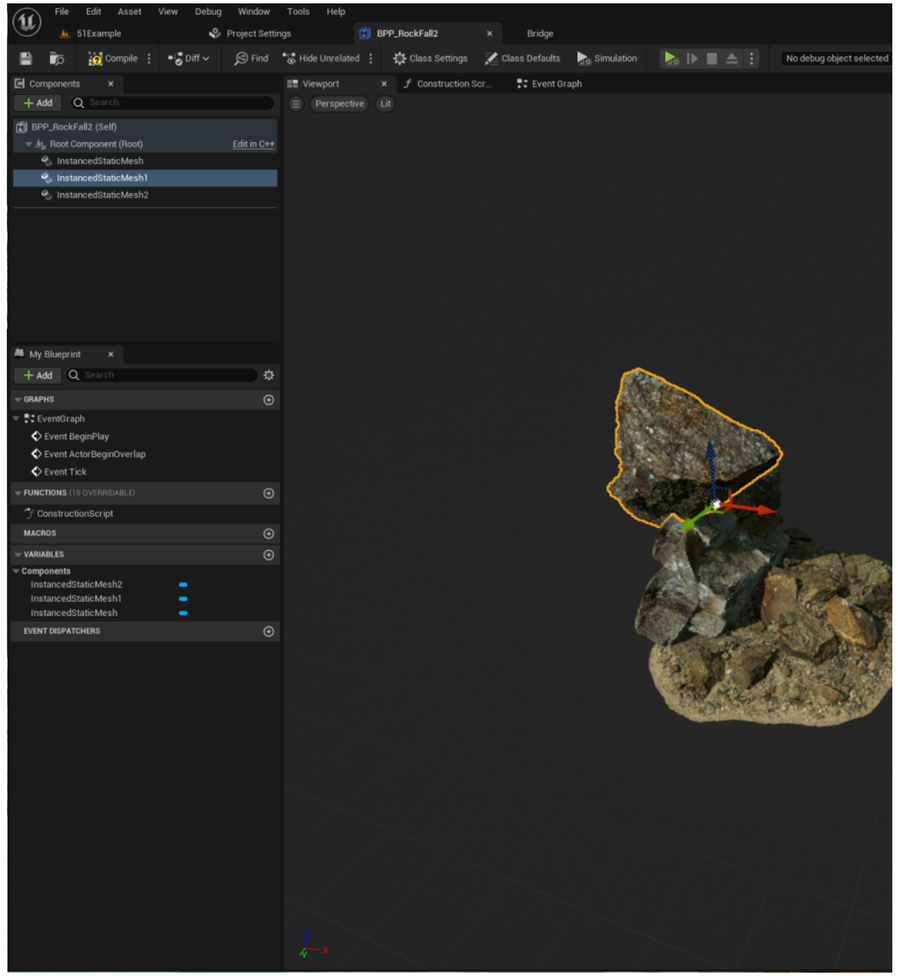

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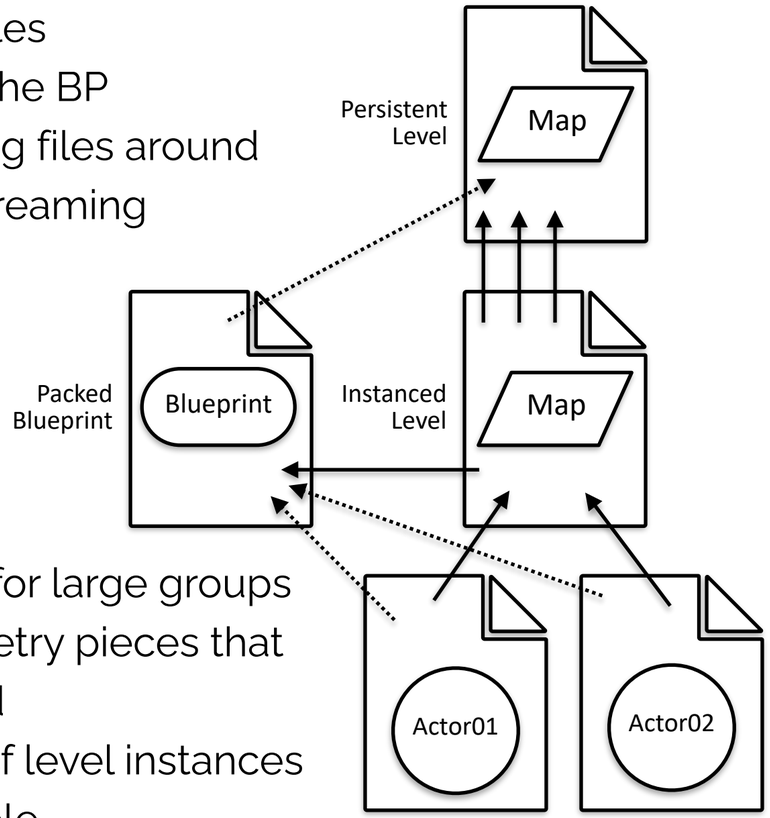

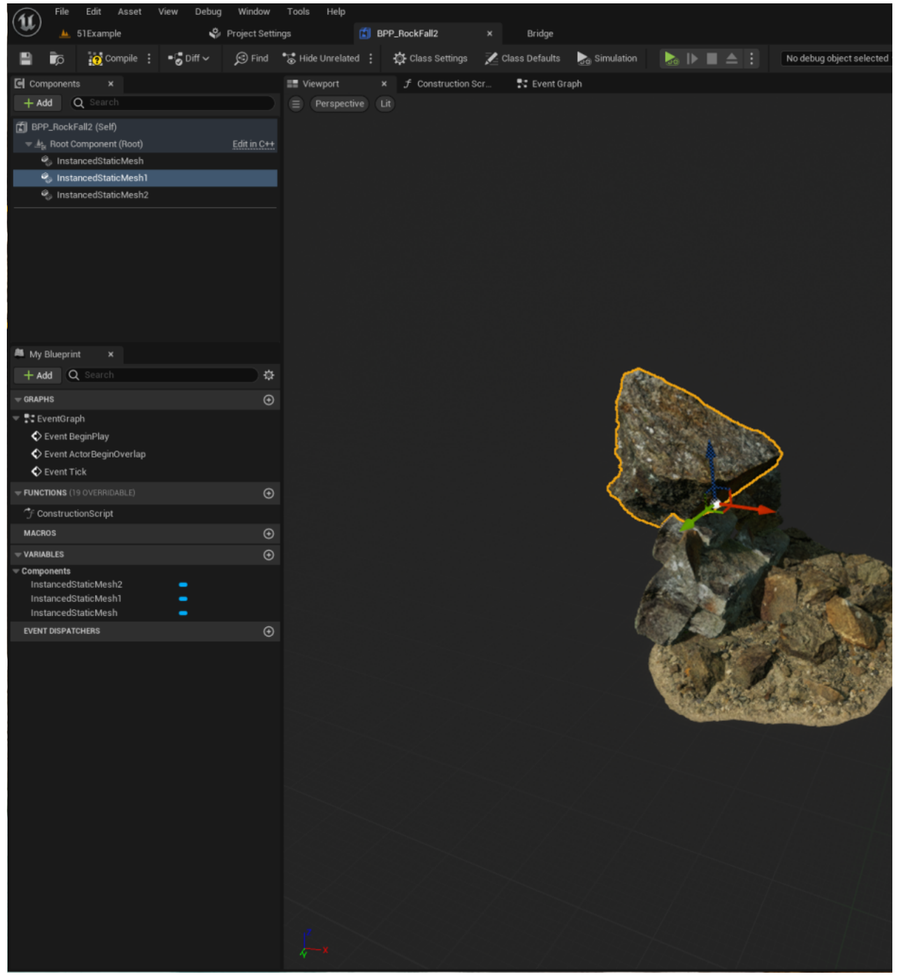

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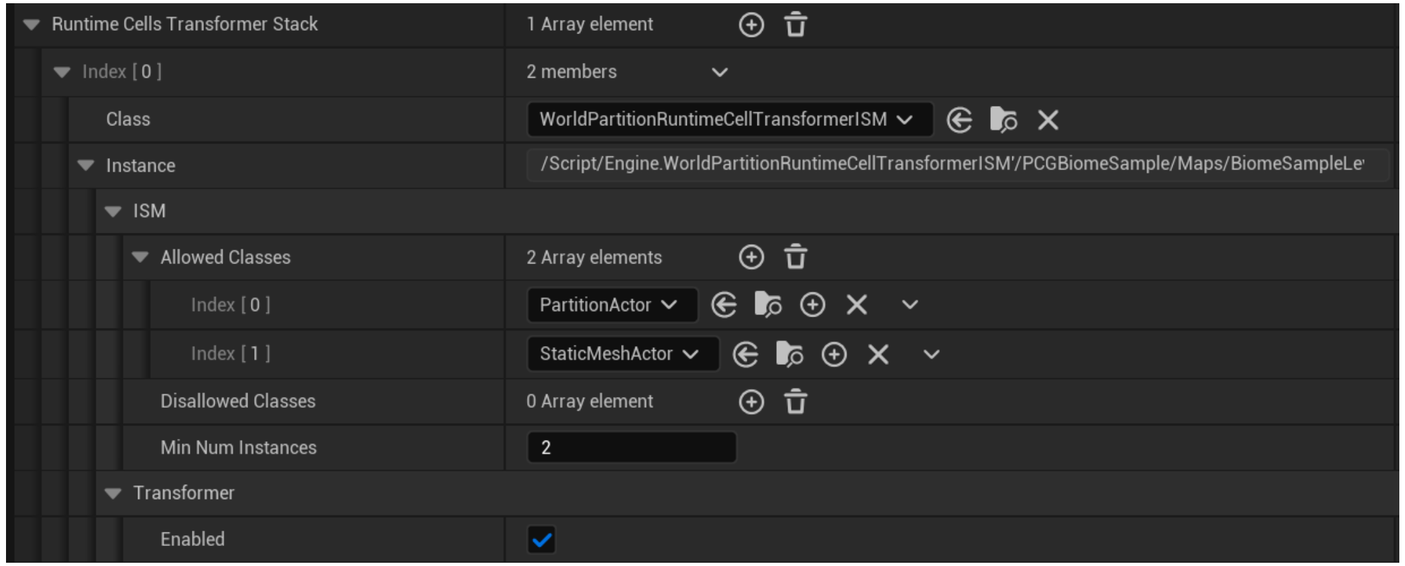
Runtime Cell Transformers

- Load and apply arbitrary transformations for actors on a cell-by-cell basis
- Only occurs during streaming generation, not saved
- While for build this is done for all cells on all grids at cook time, it is done on-the-fly during PIE sessions as grid cells stream in



"Runtime Cell Transformers are non-destructive stackable data transformation processes that are applied during the streaming generation phase when cooking and launching into PIE." - Epic's World Building Guide

World Partition Builders

- Arbitrary jobs that can be run incrementally across a World Partition level by cell
- Epic provides a number of these exposed by default under the “Build” menu
- Allows for definition and registration of custom builder commandlets

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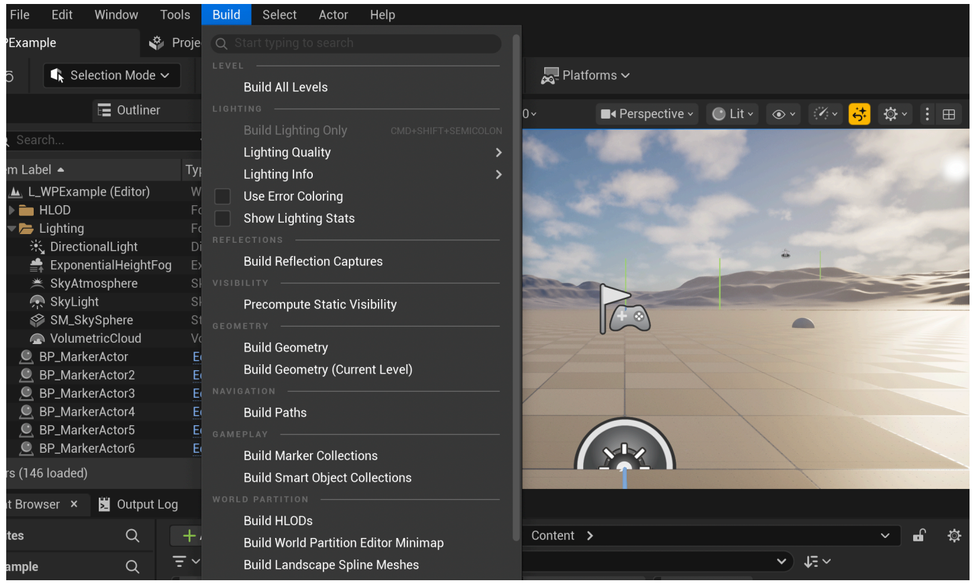
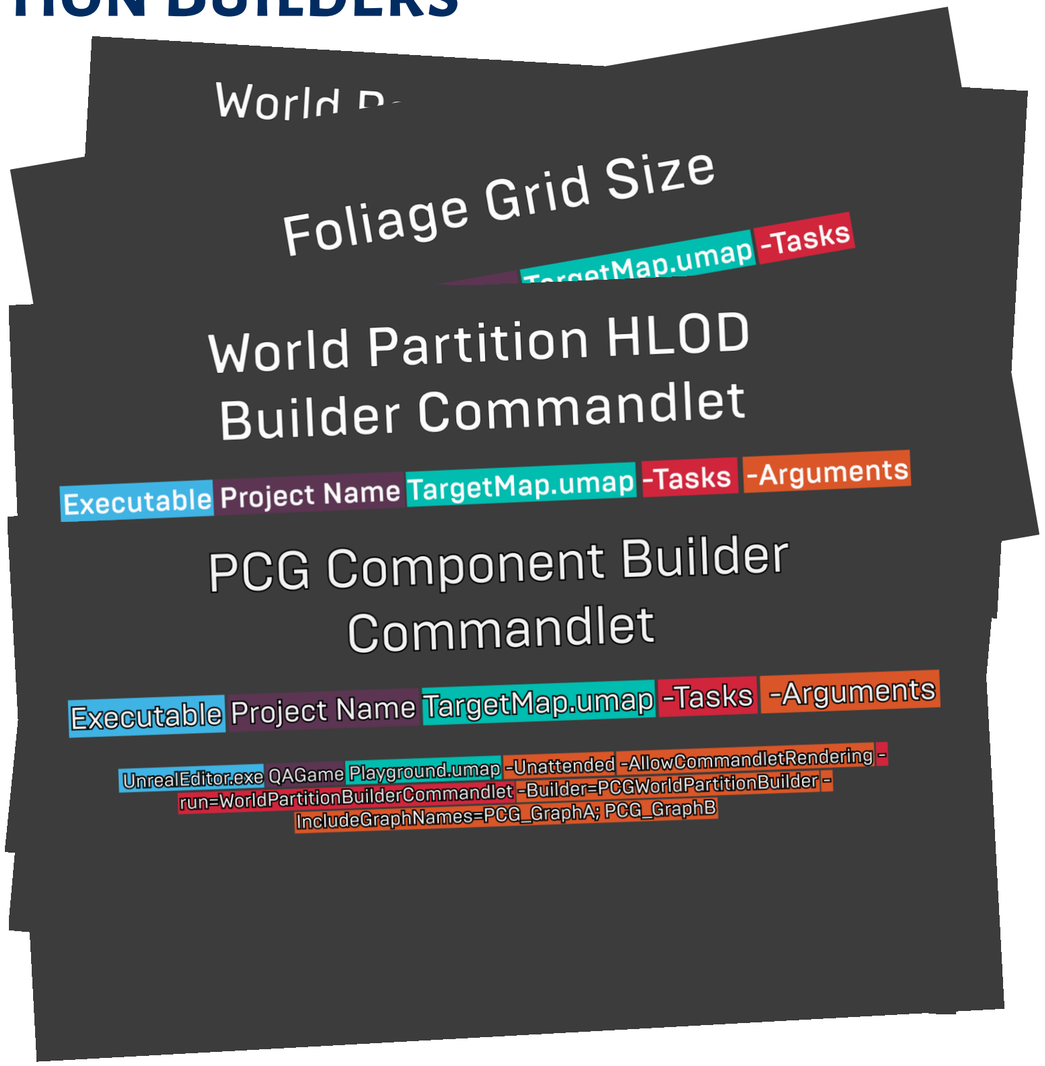
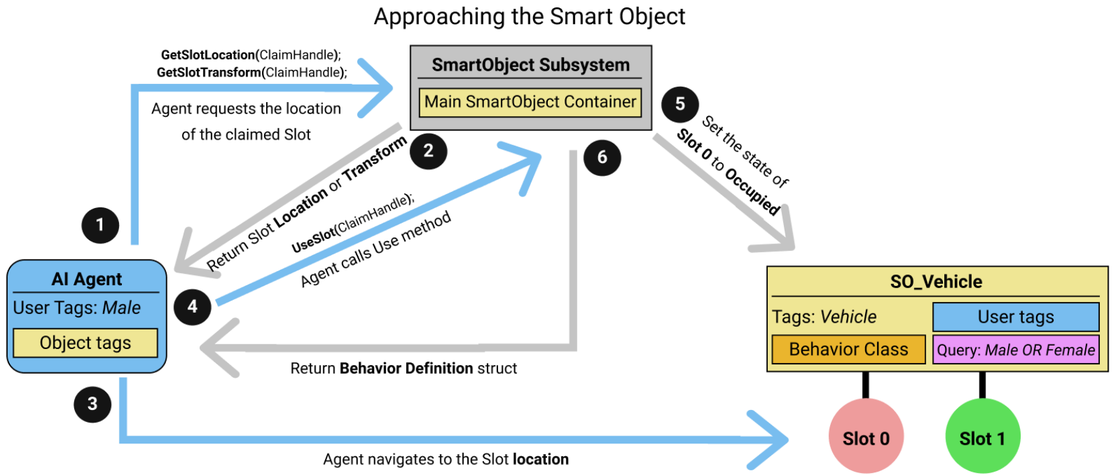




Smart Objects

- Provide tools for agents to interact with “slots” via a reservation system
- Actors with **USmartObjectComponent**s can be configured with definitions that can hold arbitrary data, or even take control interacting agent behaviour on each slot
- When searching via the subsystem, a limited subset of slot data for currently unloaded Smart Objects can still be retrieved
- Slots held in spatially-partitioned container:
  - Spatial Hash Grid
  - Octree



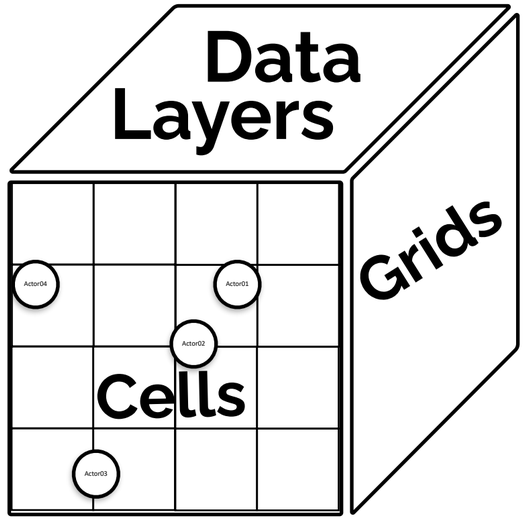
Streaming Systems For Game State Management

A Typical Open World

- Non-linear progression
- Main quest-line with lasting world effects
- Side quests with player ability to drop-in/drop-out
- Interactive map with point of interest markers
- Party system for companion NPCs
- Scheduled world changes
- Time-of-day mechanics

Evaluating Gameplay Requirements

- Assess which systems of World Partition can be leveraged to build out gameplay features with respect to the needs of your game
- Keep in mind possible dependencies and combinatorics involved with both runtime management and markup



Potential Data Layer Feature Compatibility Matrix

	Common	Scheduling	Quests	Locality	Interiors	Quality	Lighting
Common		—	—	—	—	—	—
Scheduling			✔	✘	✘	✘	✔
Quests				✘	✘	✘	✔
Locality					✔	✘	✔
Interiors						✘	✔
Quality							✔
Lighting							

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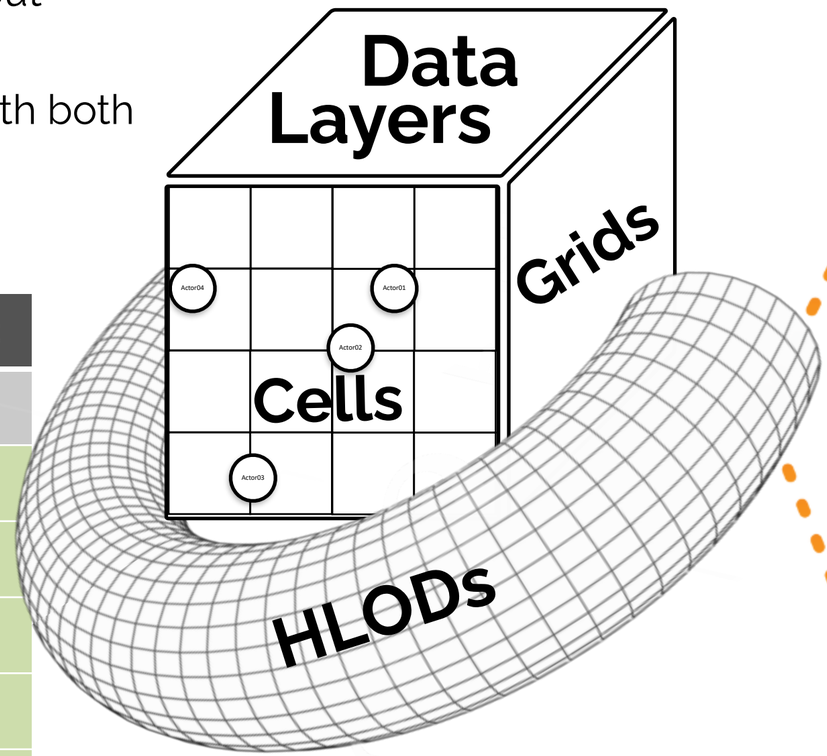
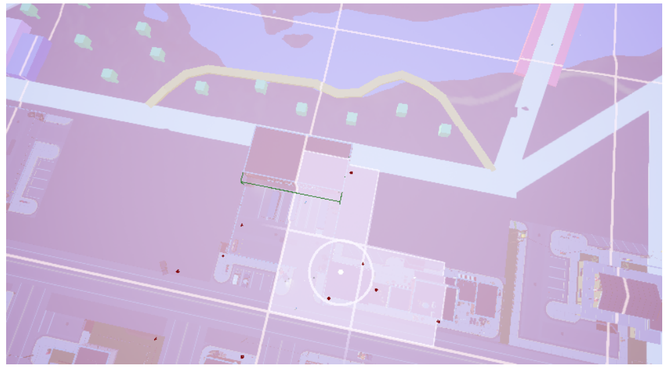
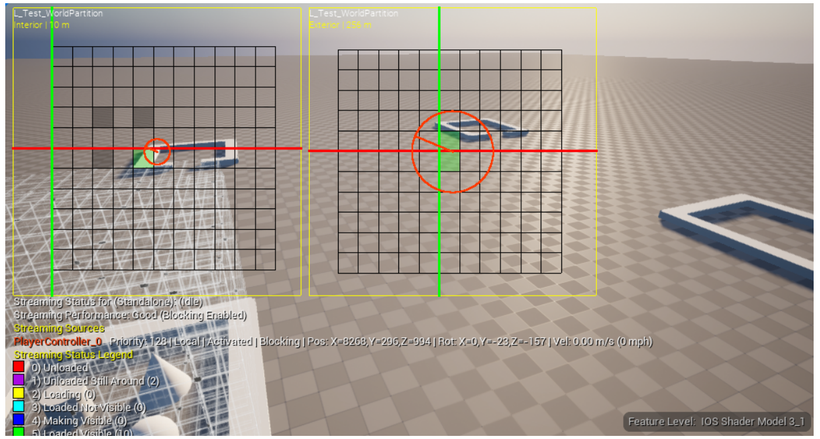
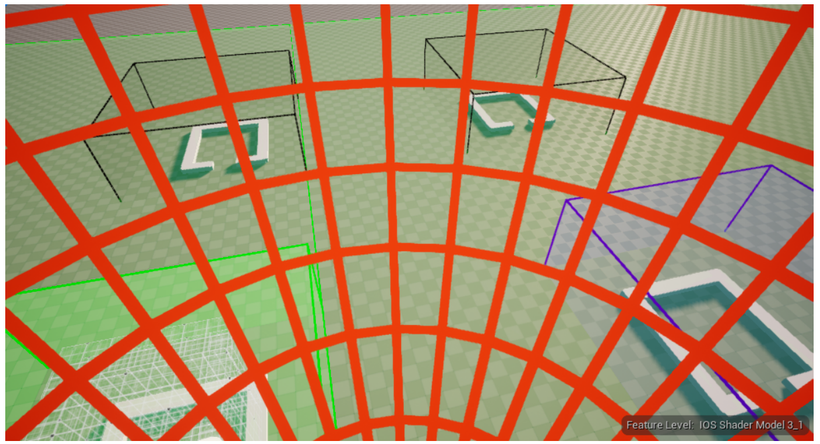


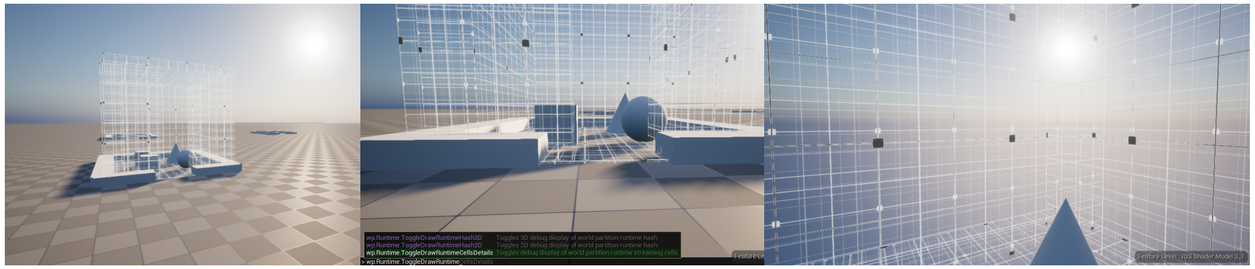
Grids As Interiors, Exteriors, & Performance Settings

- Grids used for handling interior/exterior streaming
- **UWorldPartitionMultiStreamingSourceComponent** was added to support multiple source shapes across presets
- Many interior grids is ok for level streaming
- Fully unloading exterior is not recommended unless applied to large interiors





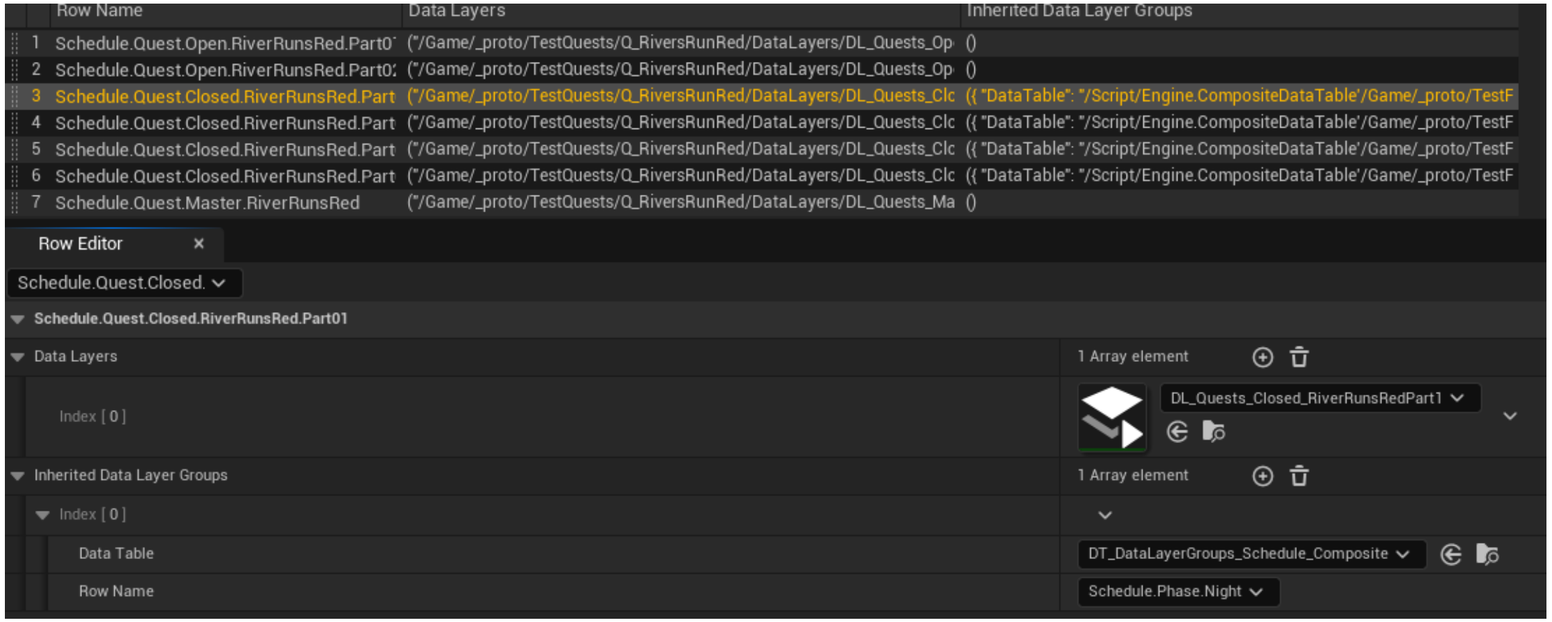


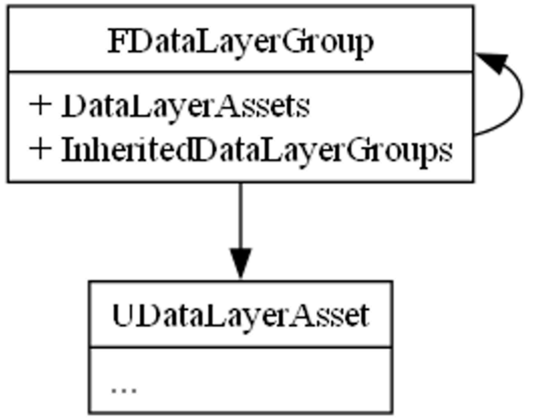


Data Layers As Schedules, Quests, & World States

- OR behaviour makes these concepts reasonably compatible
- Data Layers make for a powerful tool in manipulating scheduling

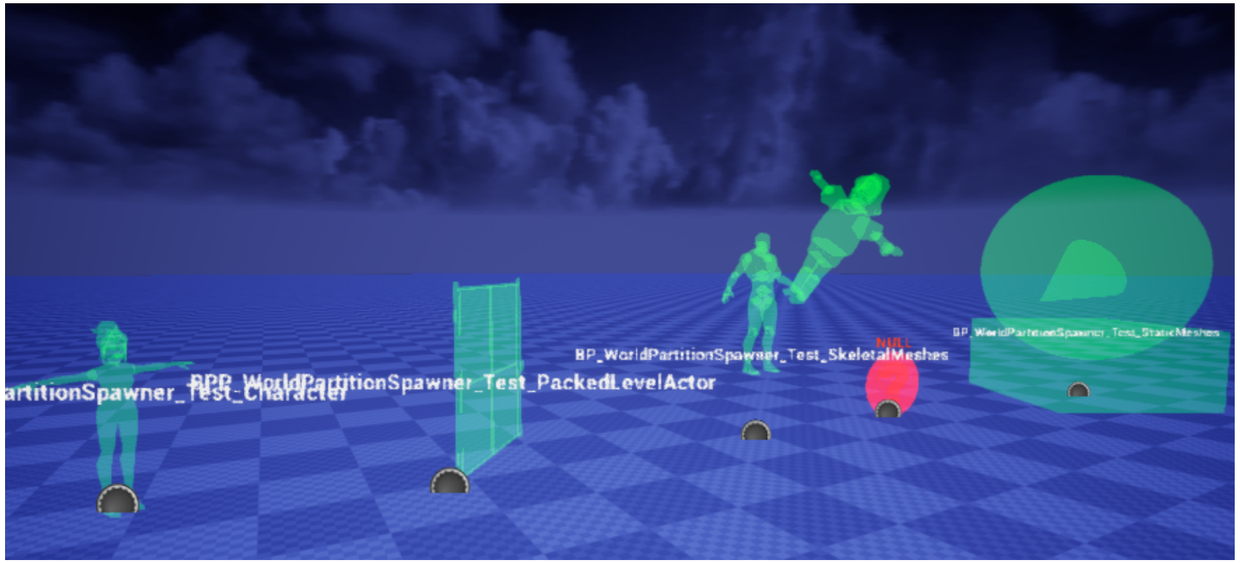
- **FDataLayerGroup** provides hierarchical specification of inherited groups
  - Multiple schedule groups can be enabled simultaneously

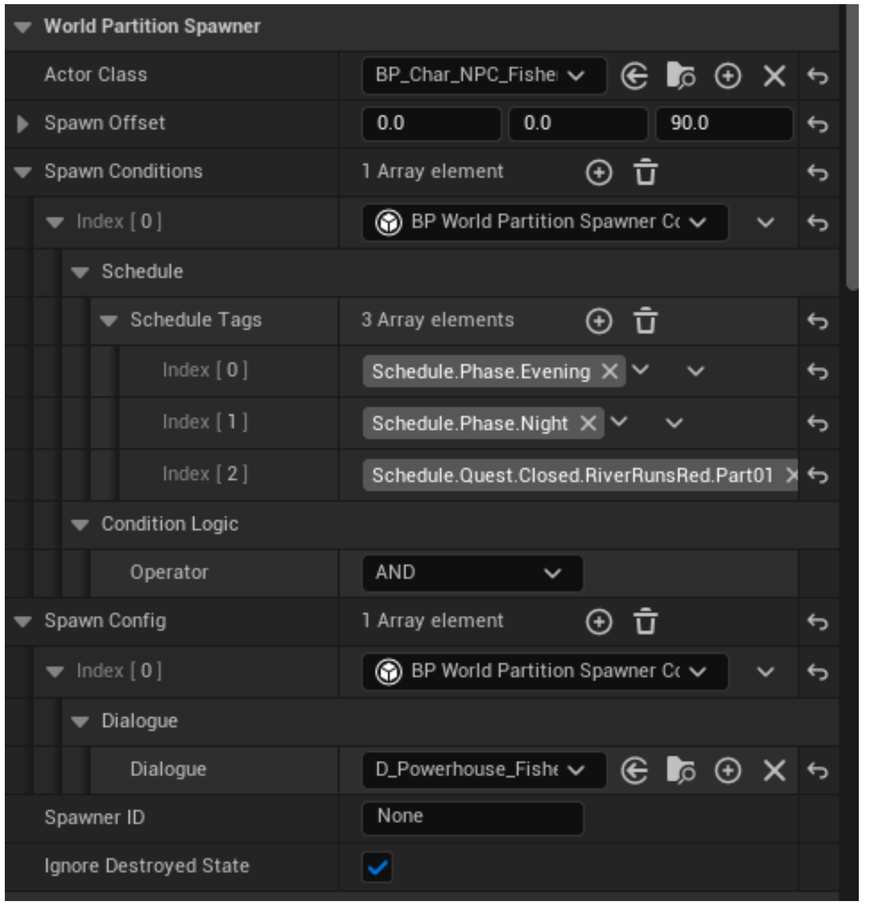




World Partition Spawners

- The limitations of Data Layers can be supplemented by **AWorldPartitionSpawner**, to finely control spawn and config
  - Data Layers used to mask higher order requirements
- Manage detaching and reattaching for ownership changes
- Can also be configured via temporary editor actor with hooks to serialise to proxy archive, stored as binary





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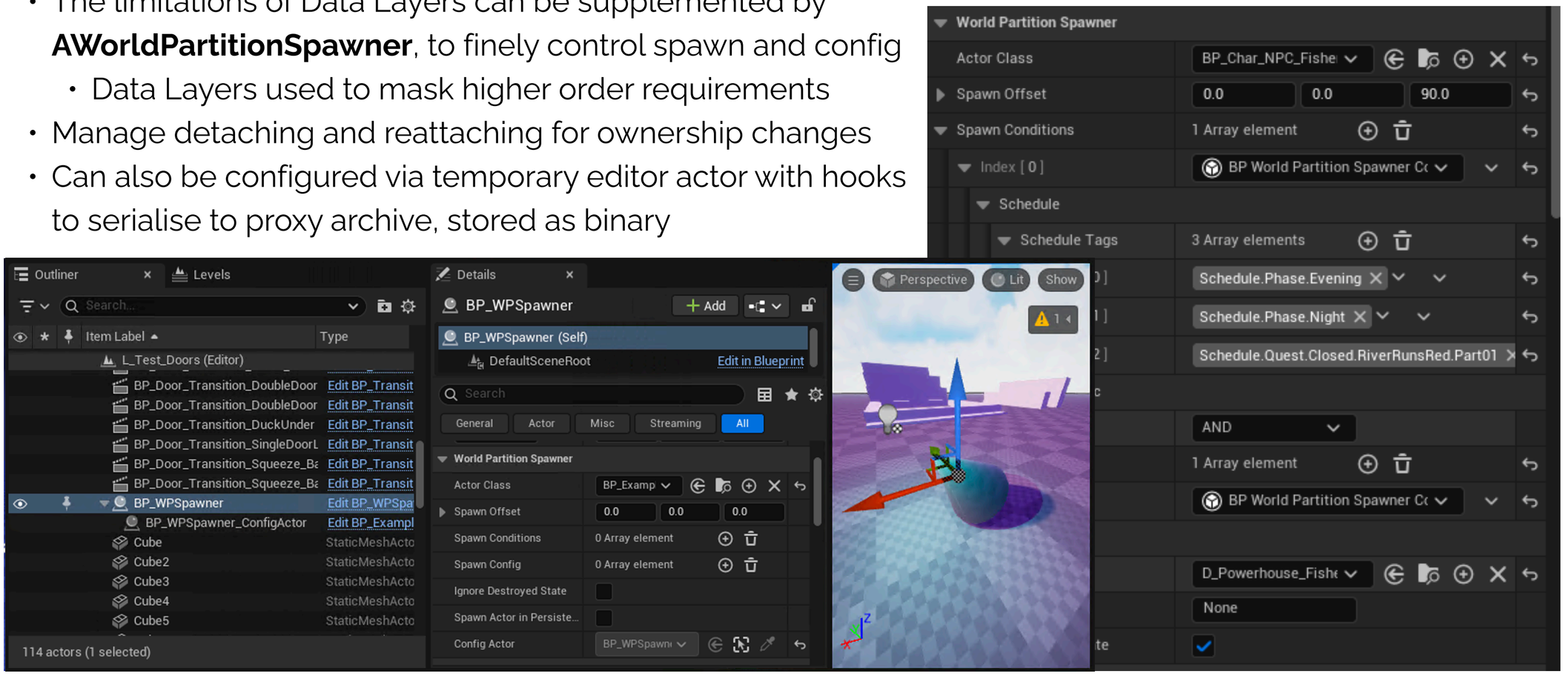

Open & Closed Schedules

- Use “open” and “closed” schedules for controlling additive world state with managed preloading

- Schedule can be modified with activation policies of:
  - **Standard:** Replace the current active schedule, keep additives
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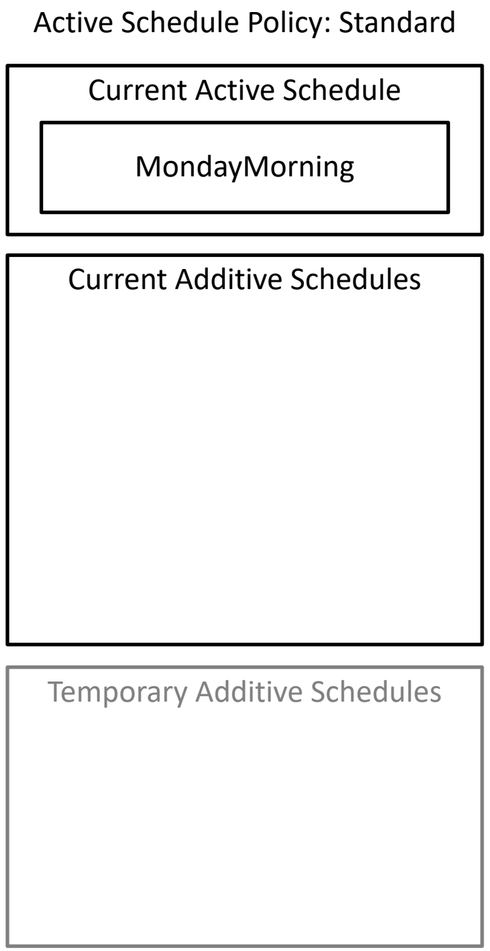
- Temporary additives can be overlayed during solos for finer controls - will be discarded on policy change
- Persistent schedules allow world state to affect all policies

- Can be linked to the lighting and environment systems to force certain properties such as time-of-day and weather conditions



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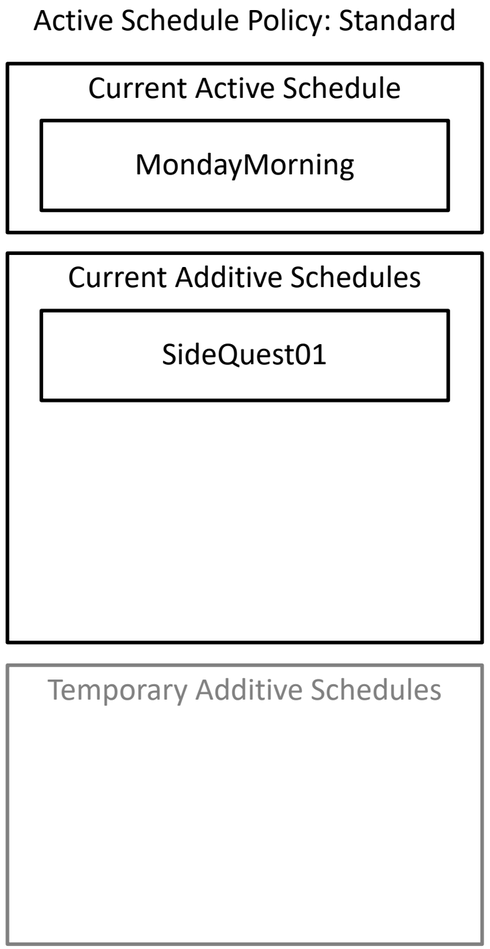

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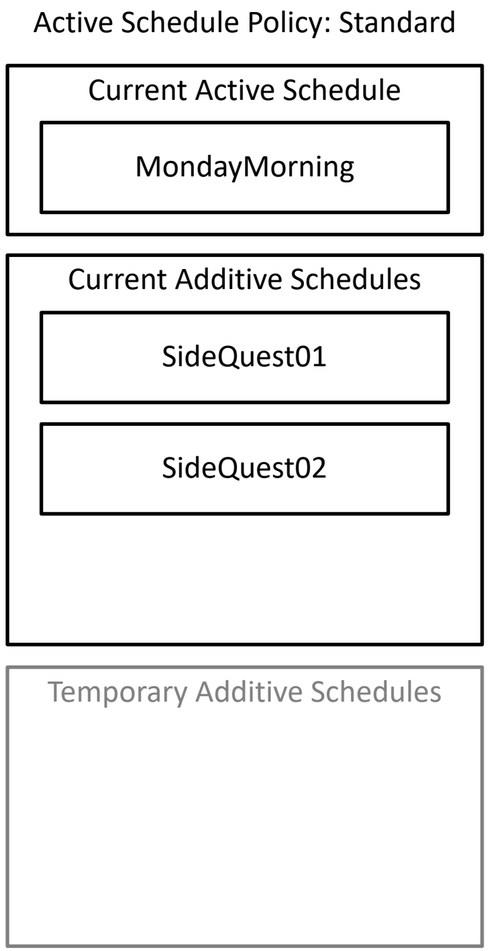

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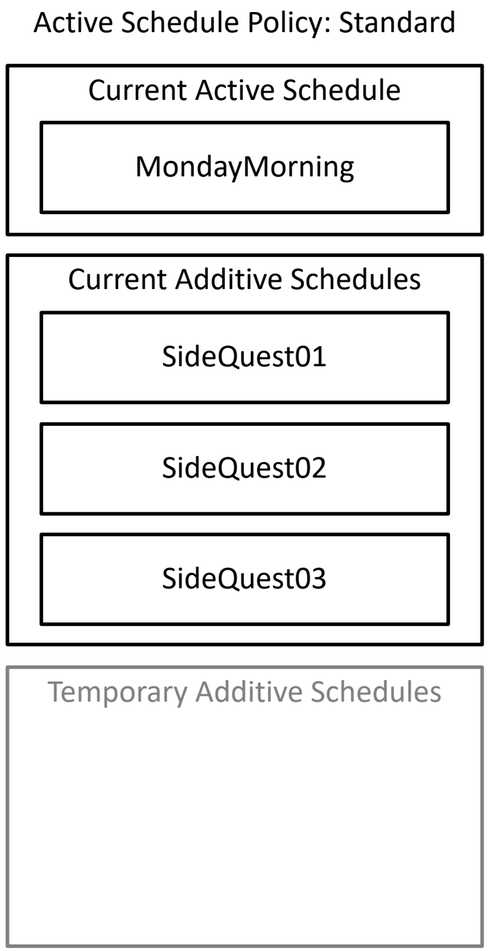

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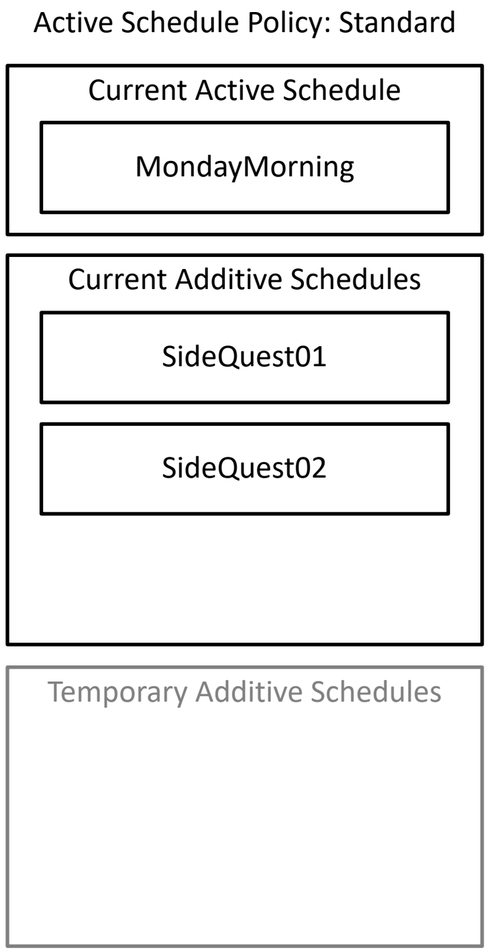

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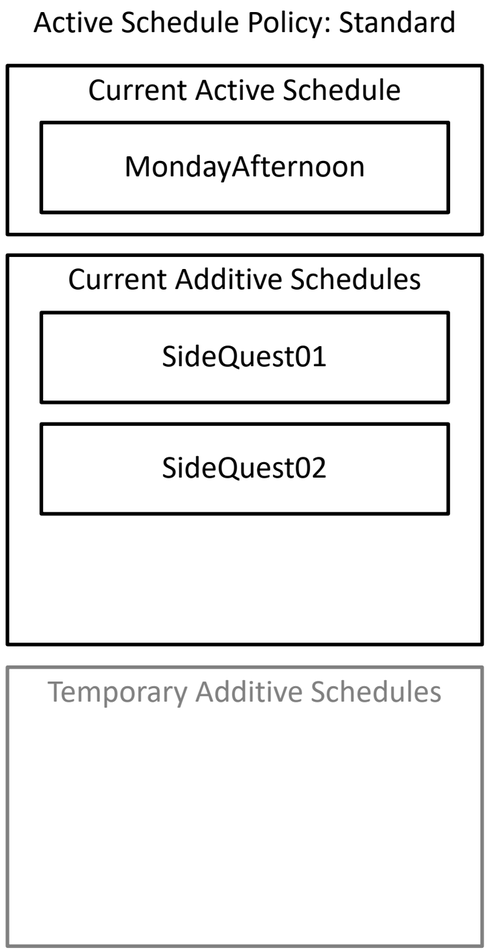

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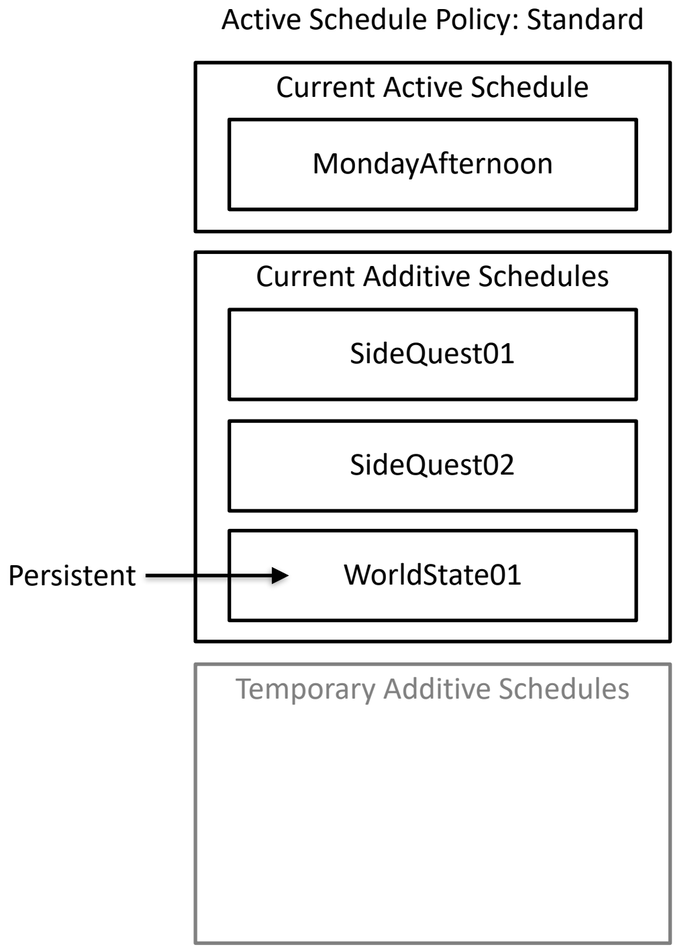

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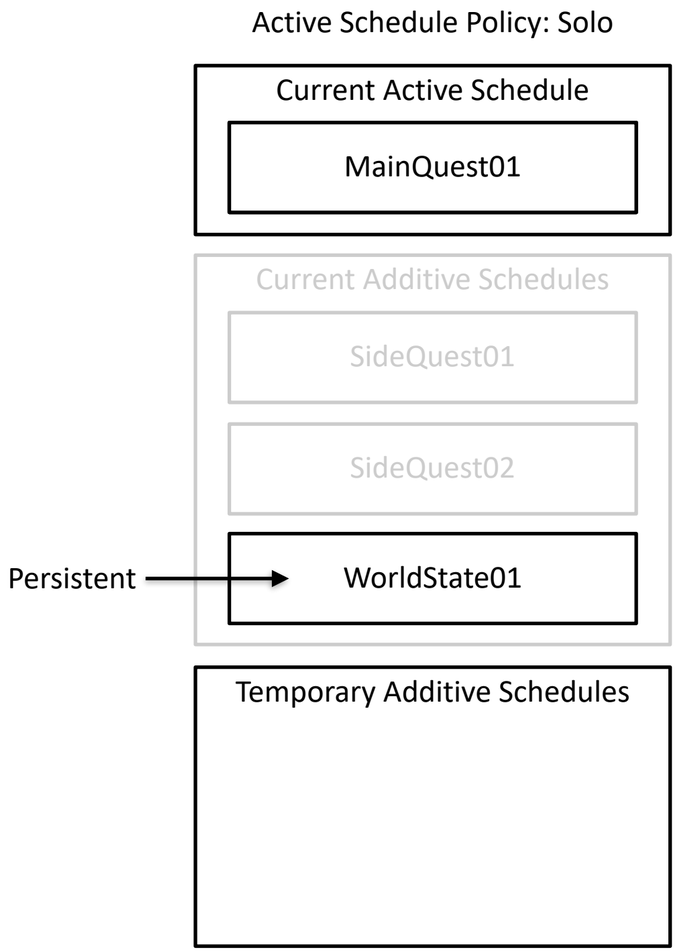

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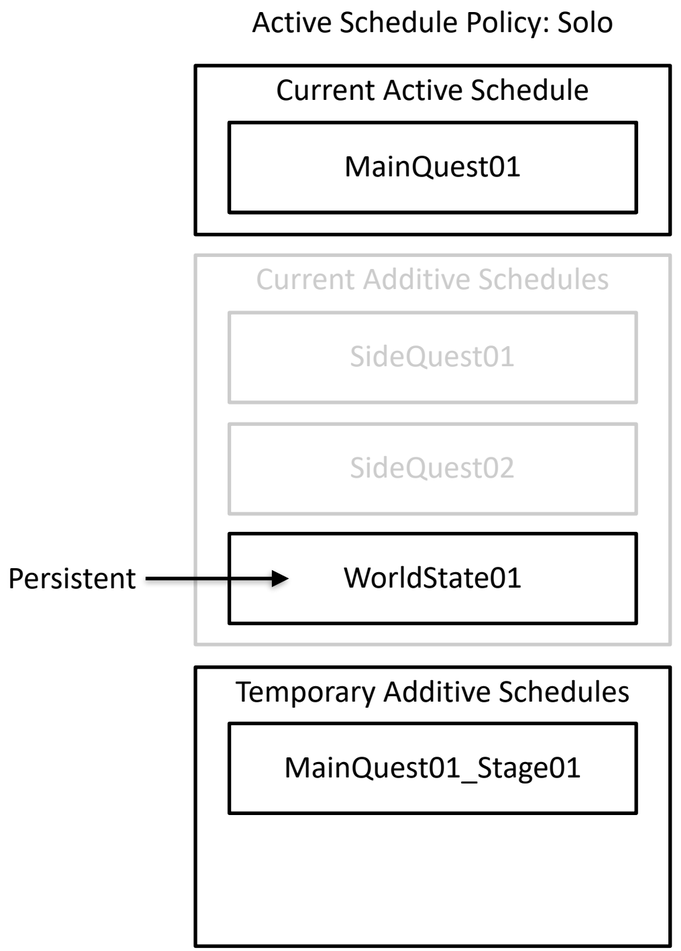

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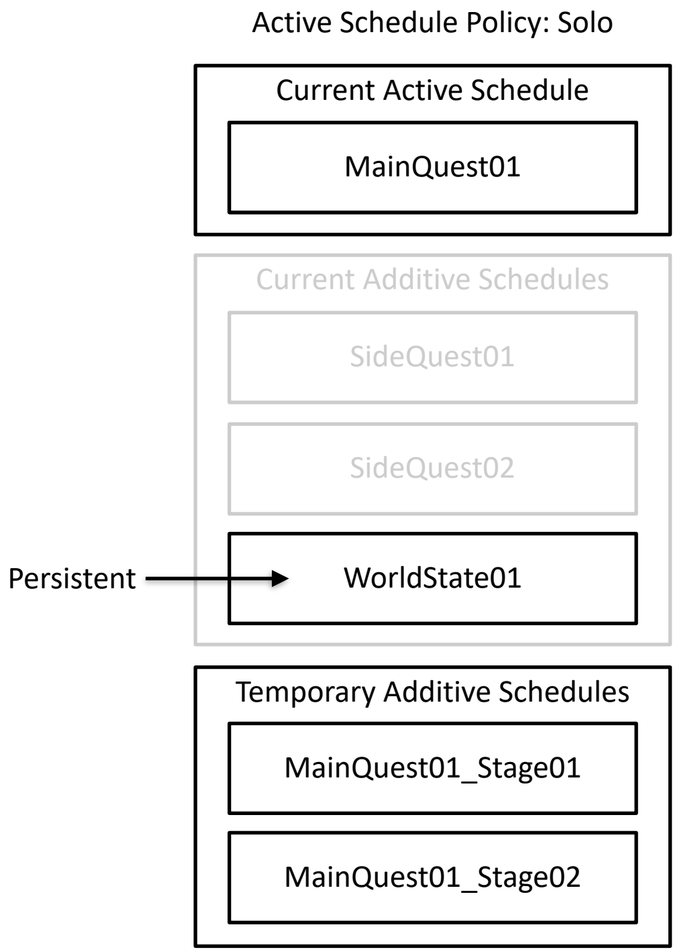

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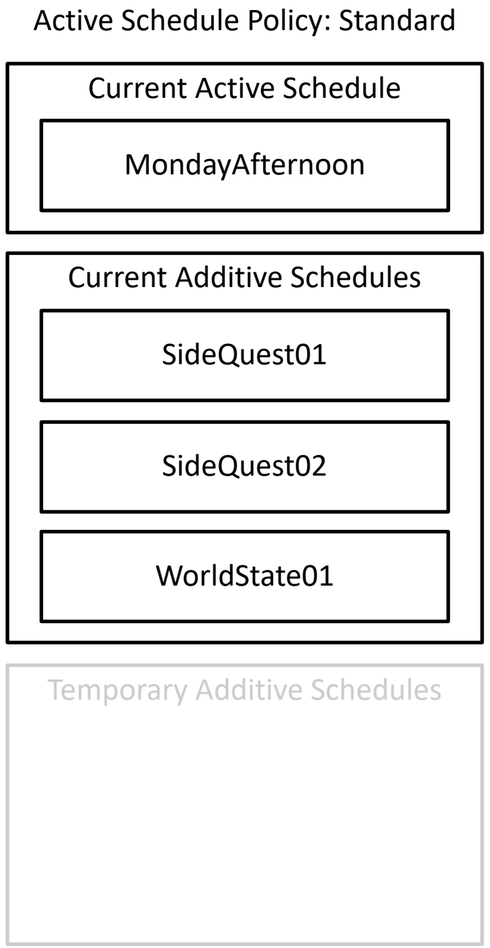
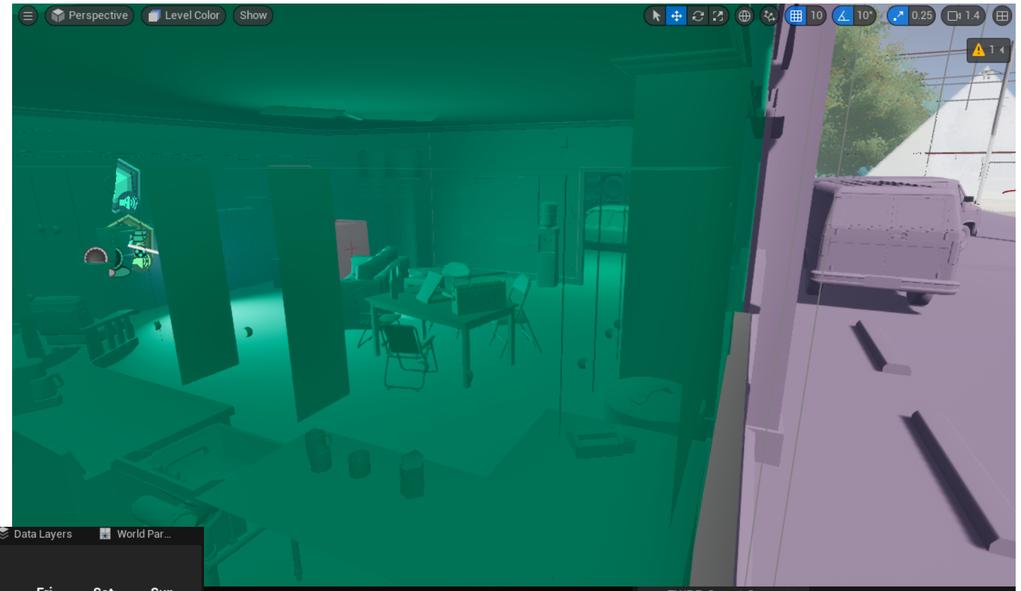
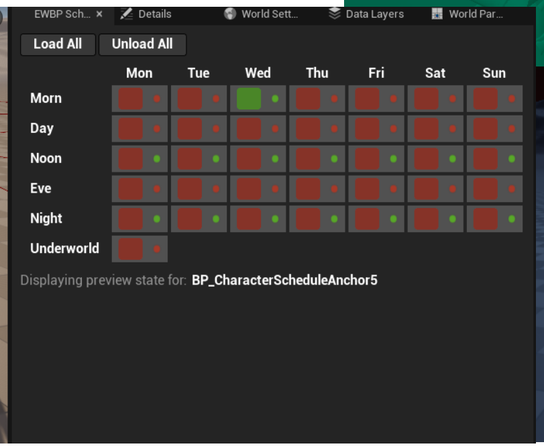
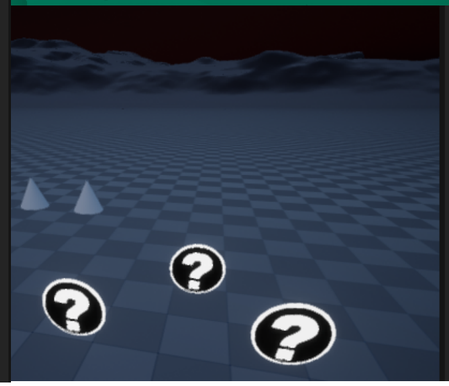


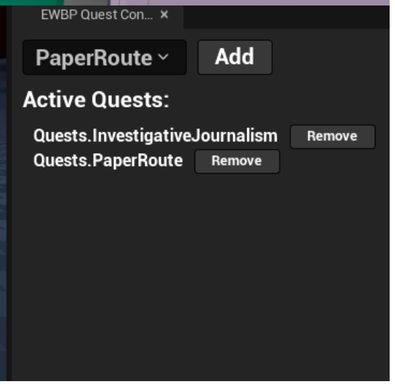
Custom Markup & Tooling Workflows

- Runtime Streaming Grid Actor Colouration
- Character Appointment Spawners
- Lighting previews alongside schedule in-editor
- Schedule preview & management controls









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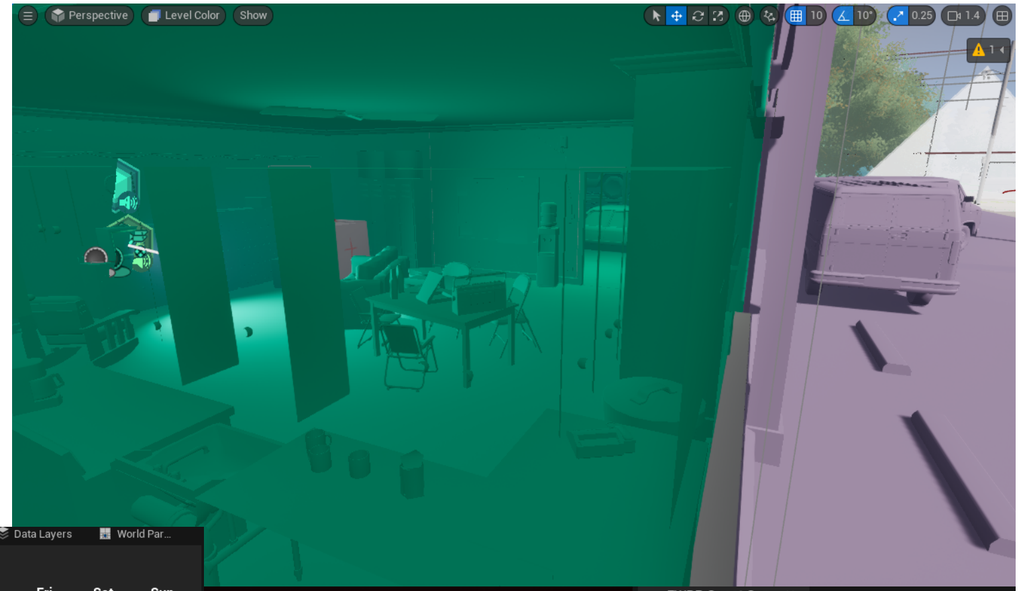

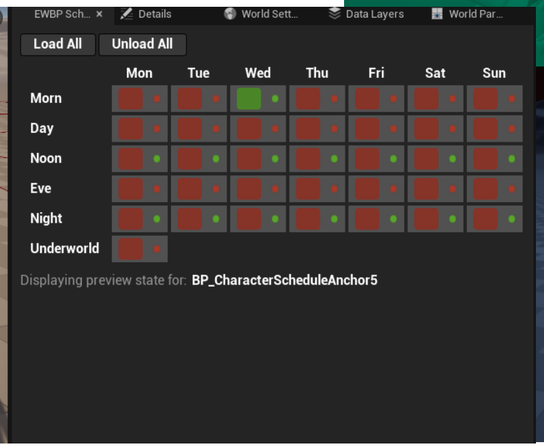

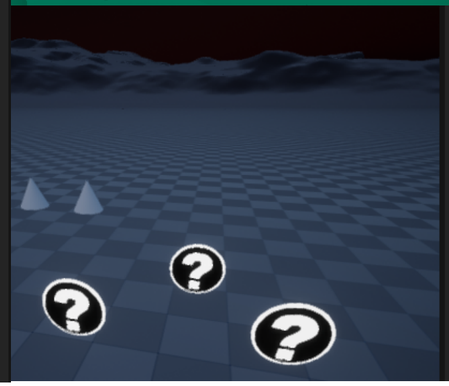

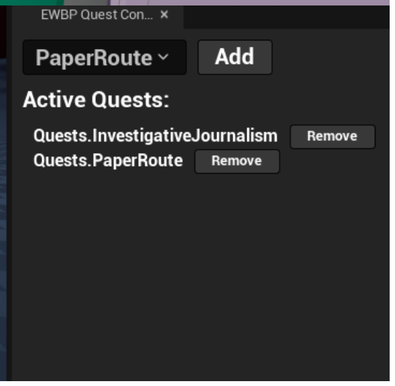

Level Streaming Watch

- The **ULevelStreamingWatch** object allows owners to easily bind to and query world streaming state for either the whole world or just for a specific source
  - Helps handle slow streaming and provides feedback for dependent features

- Used across several systems to manage streaming-aware functionality:
  - World startup and configuration
  - Teleportation warm-up and execution
  - Interior/exterior transitions
  - Managing airlocks between scripted level segments

A Marker System

- Keep all marker actors persistently loaded
  - Easy to understand, incredibly wasteful
- Cache markers on world startup with Data Layers
  - Easy in PIE, painful and fiddly to manage
- Cache markers on cook for offline lookup, track live
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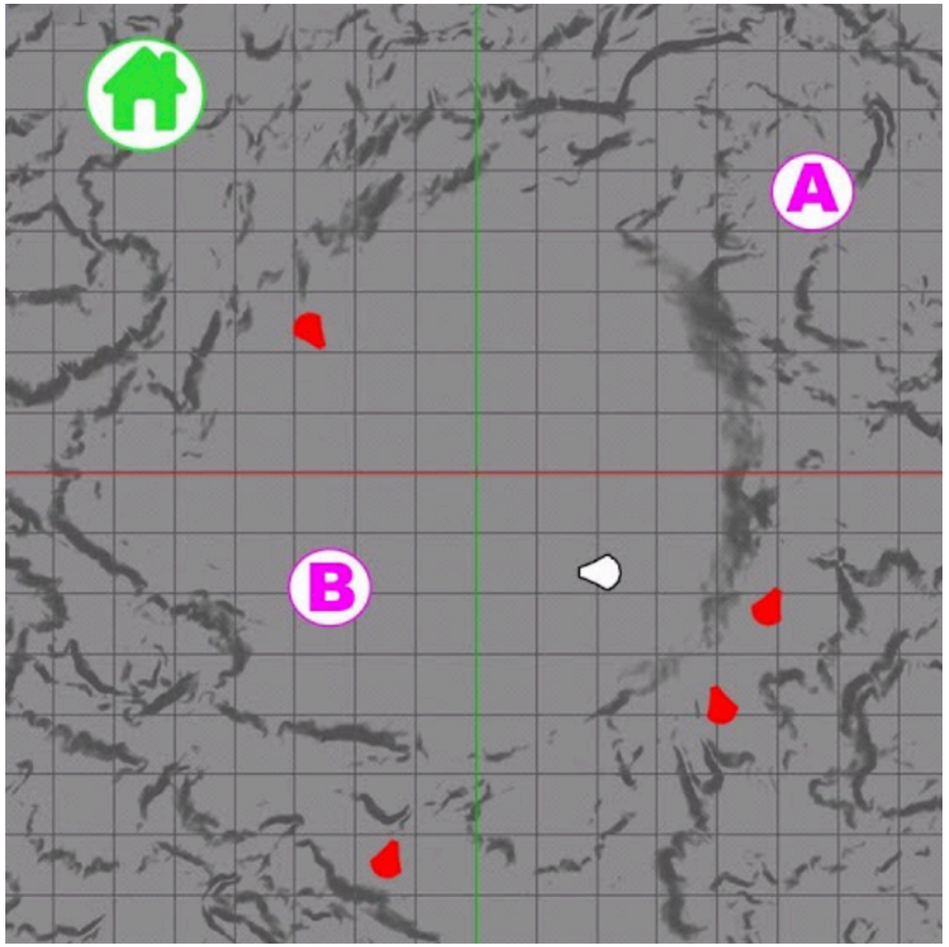

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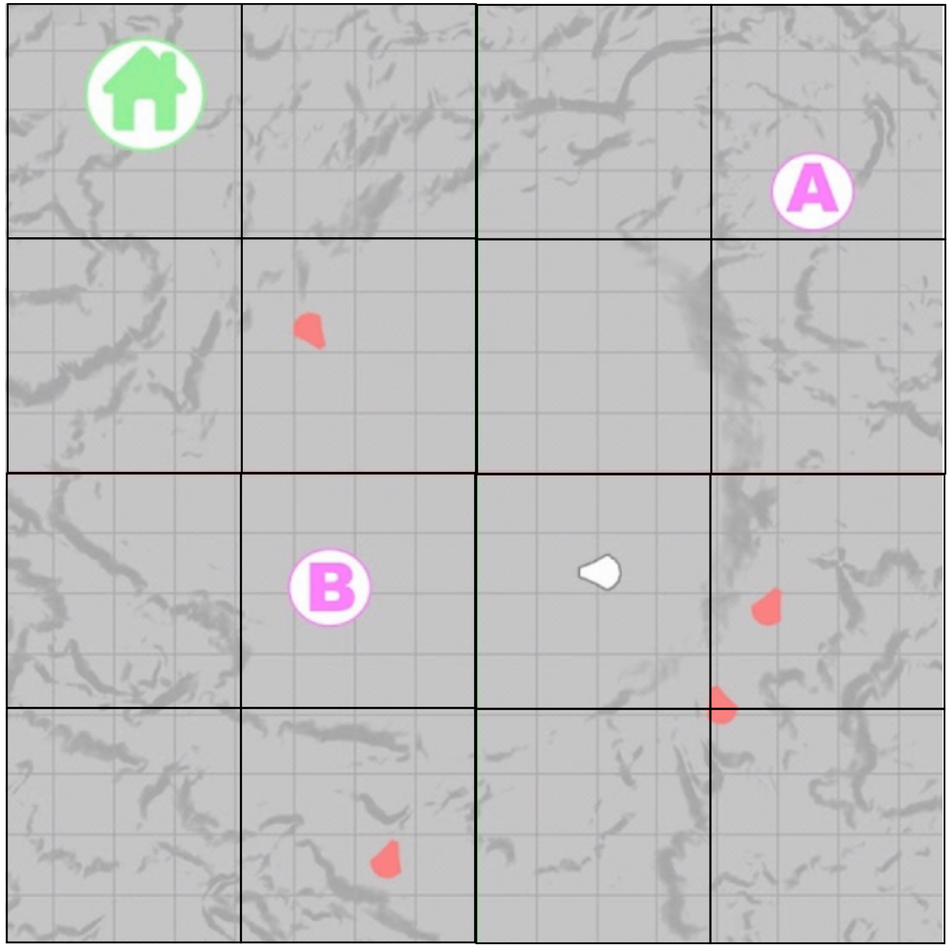

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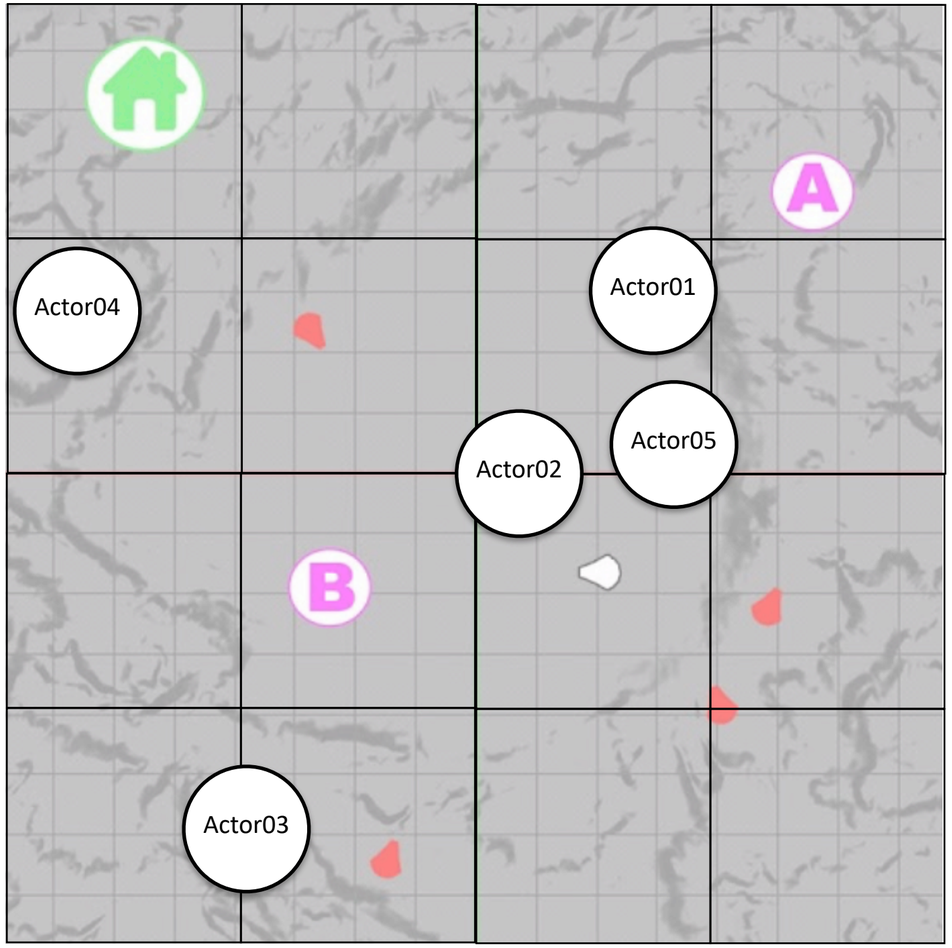

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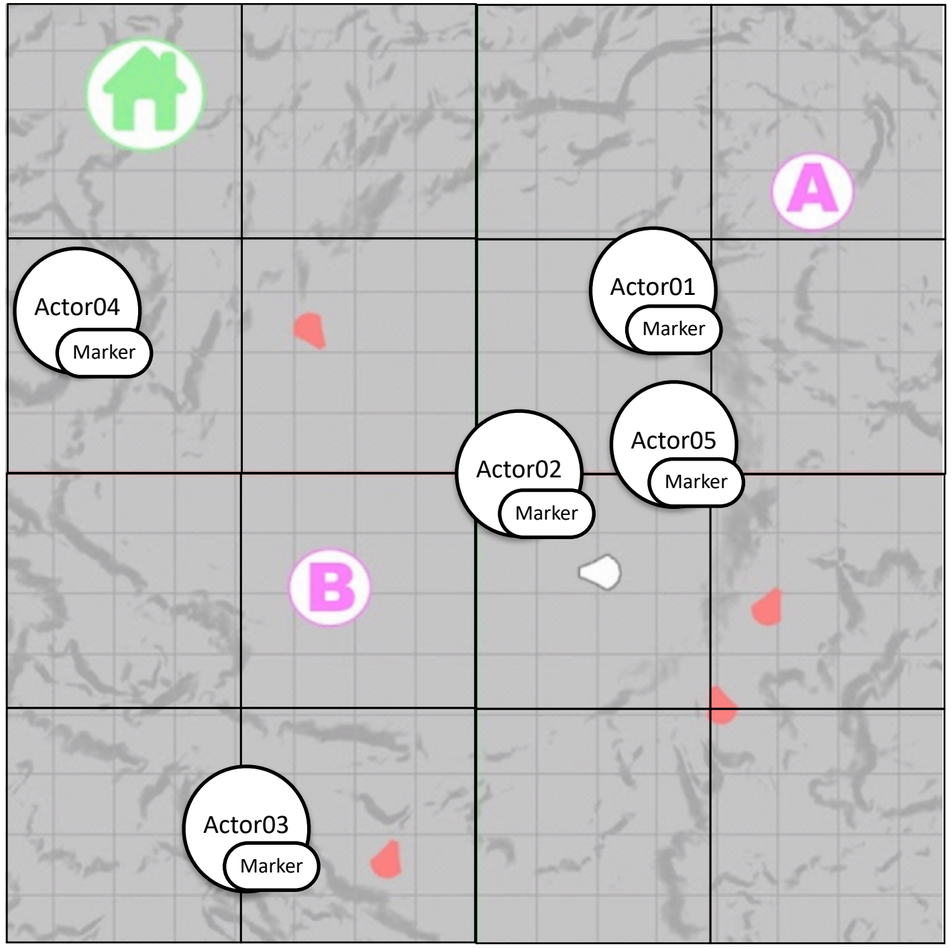

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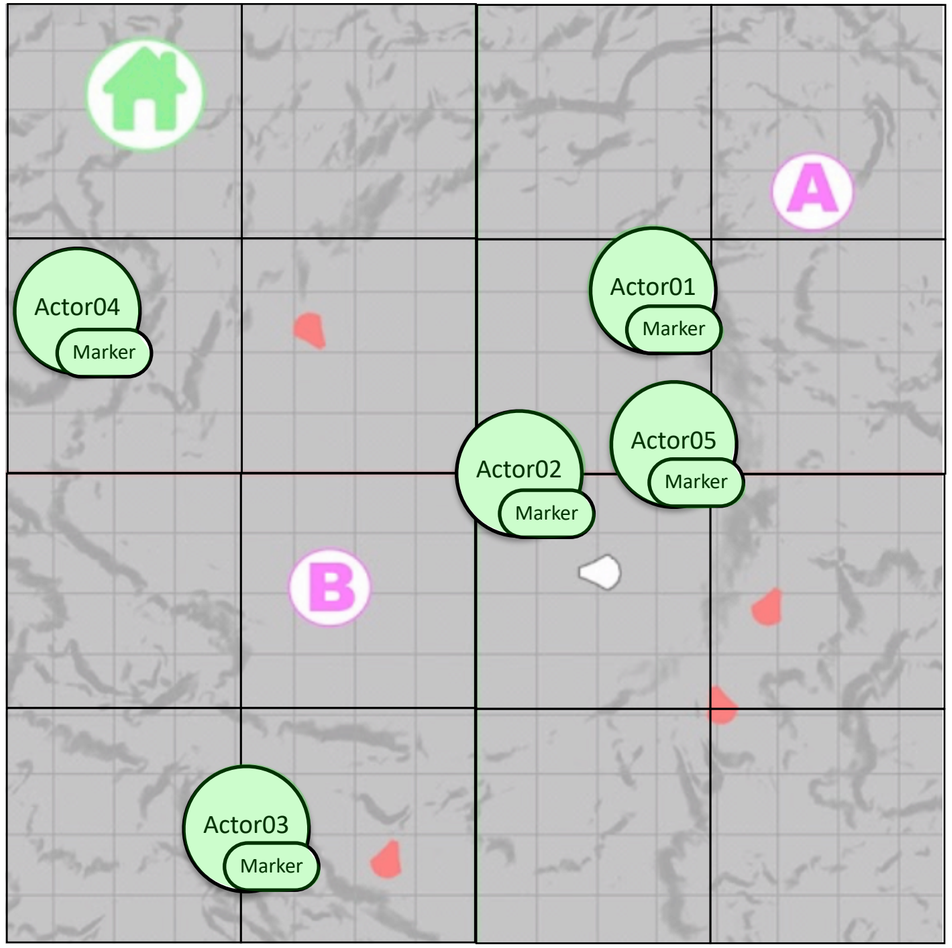

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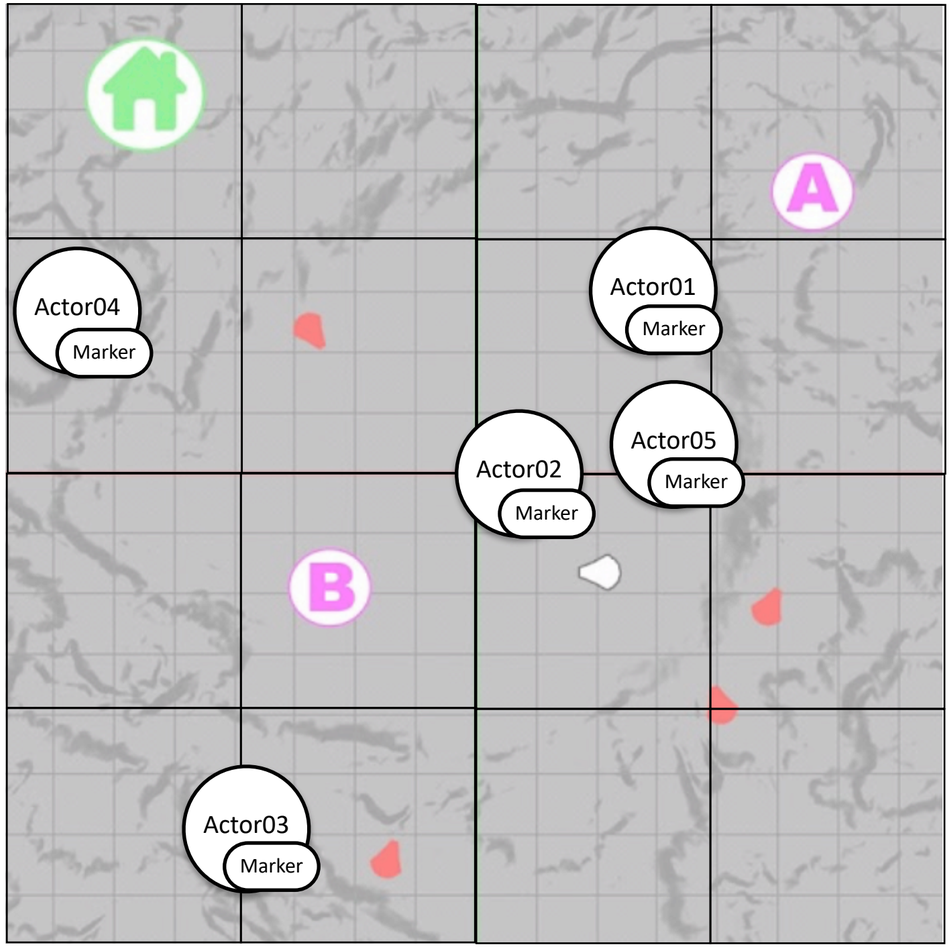

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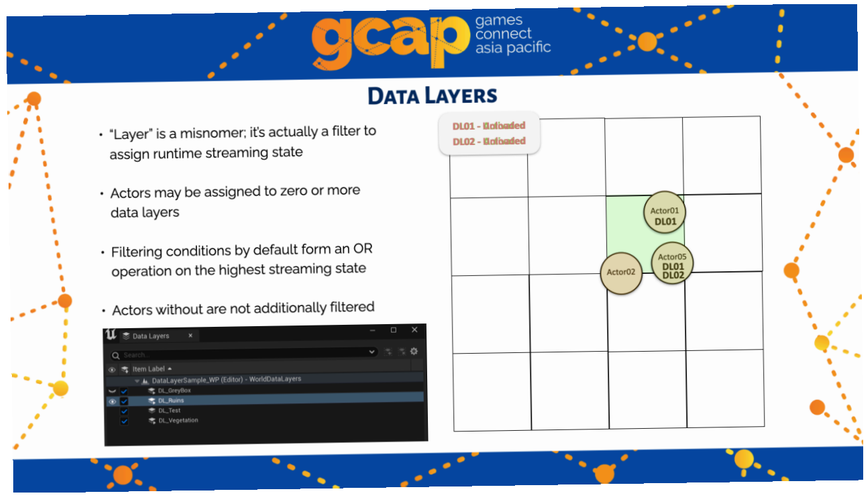

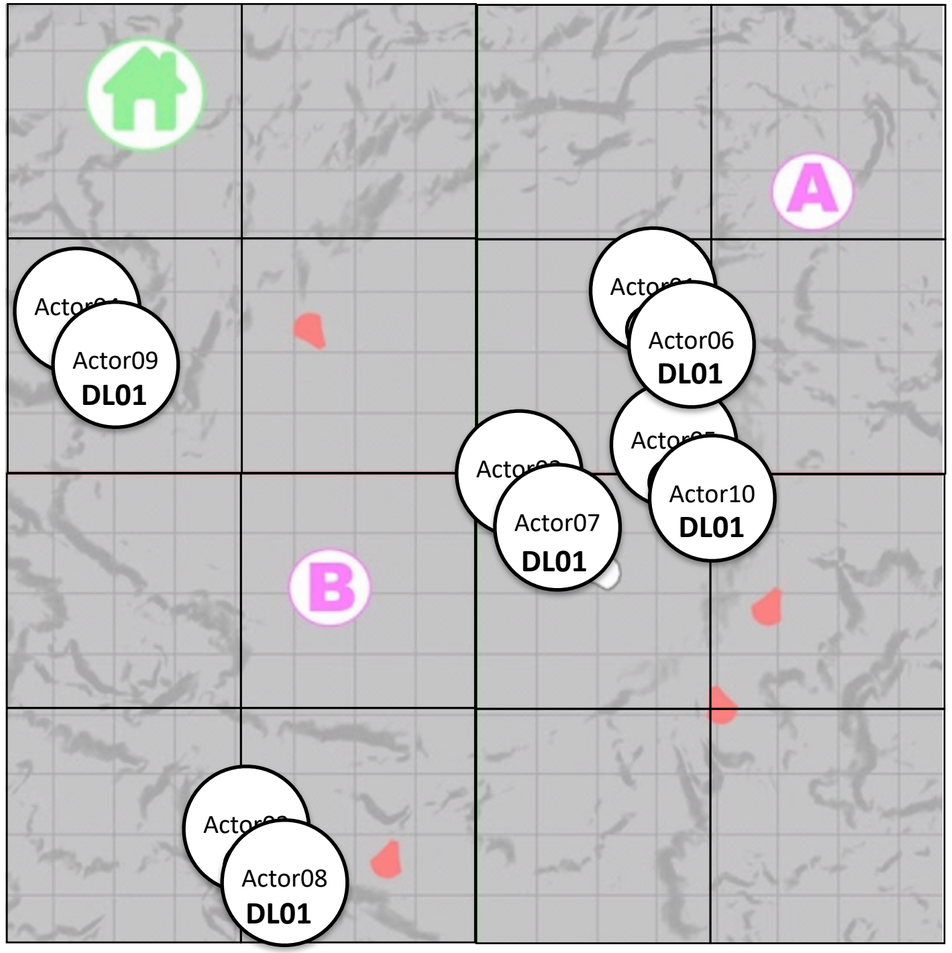

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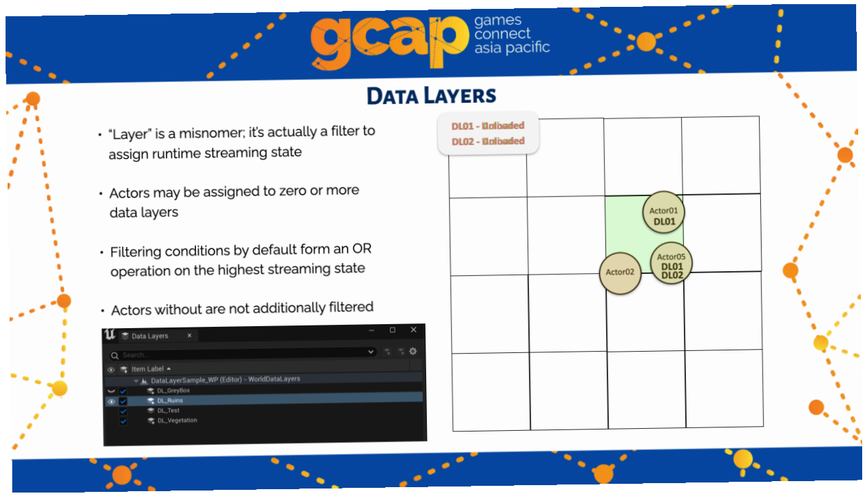

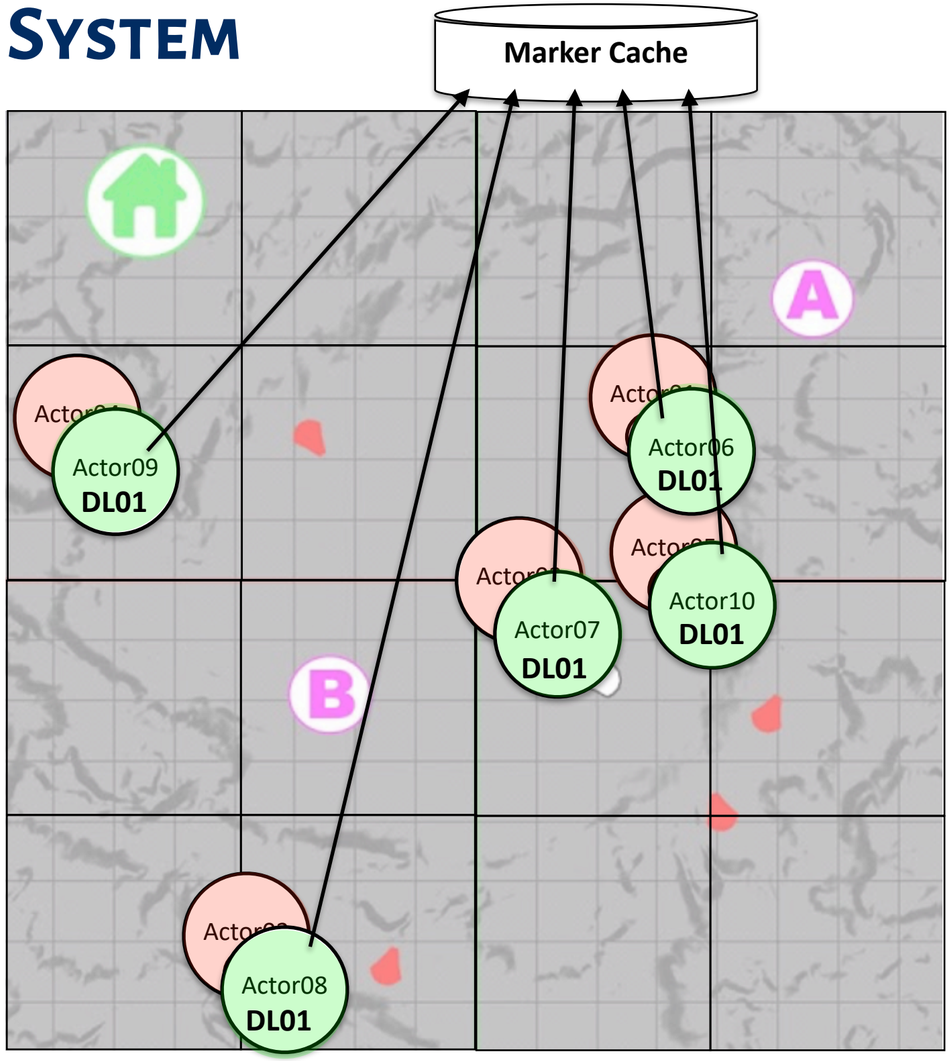

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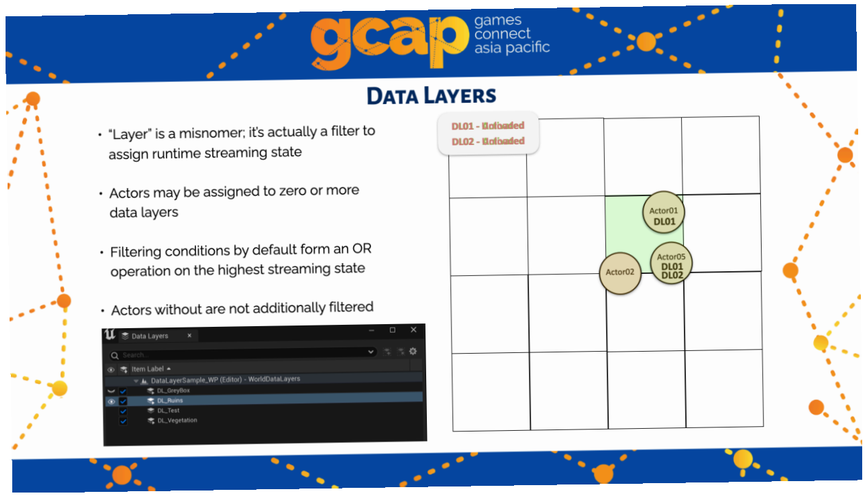

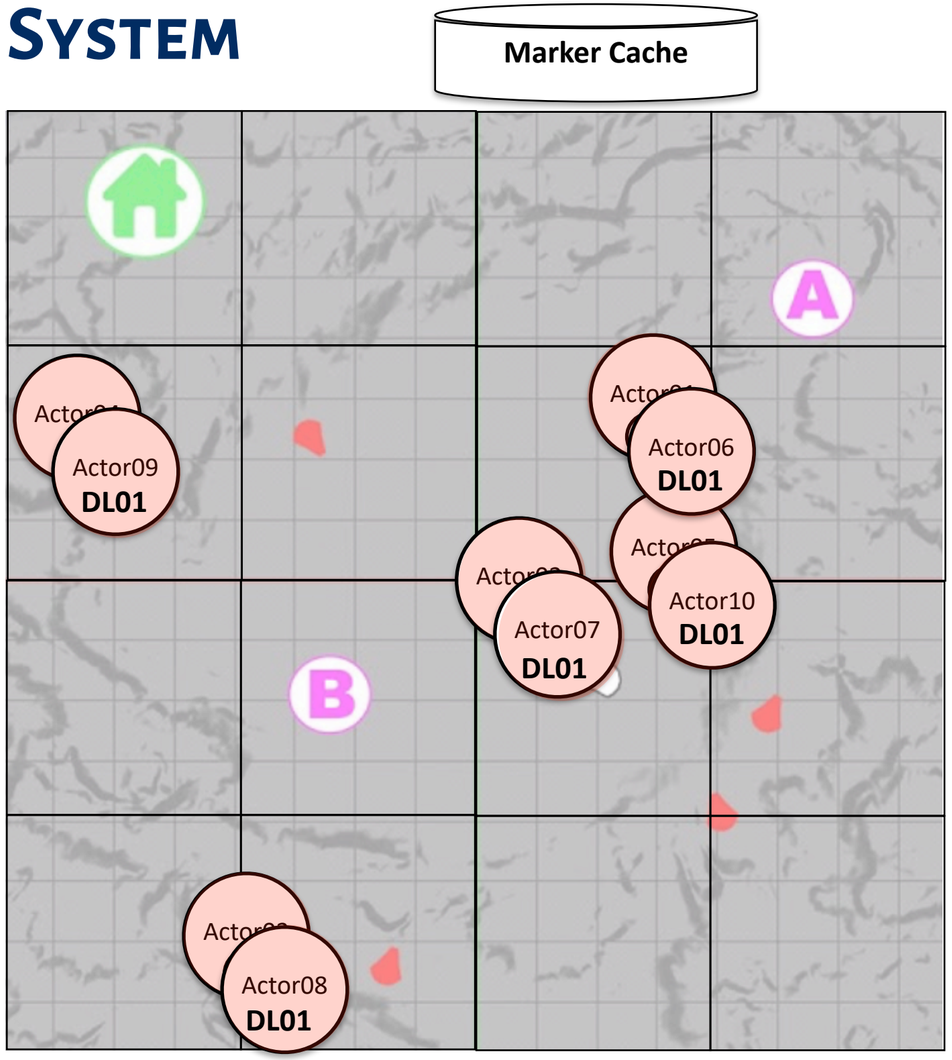

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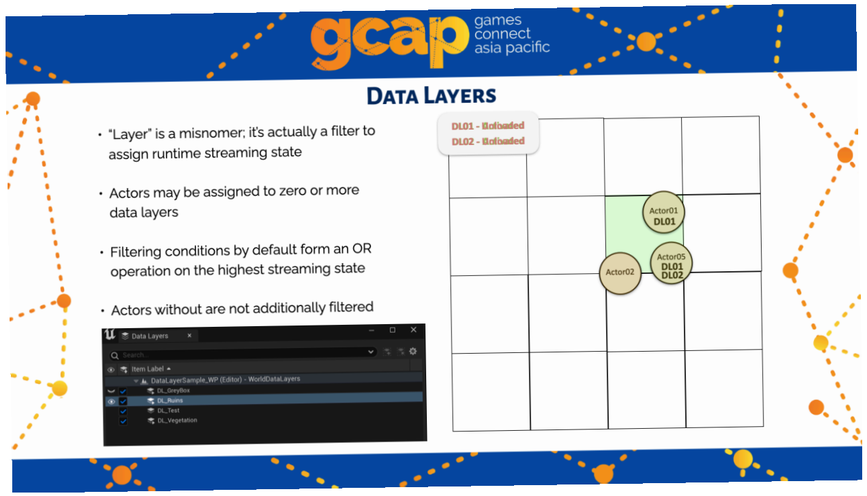

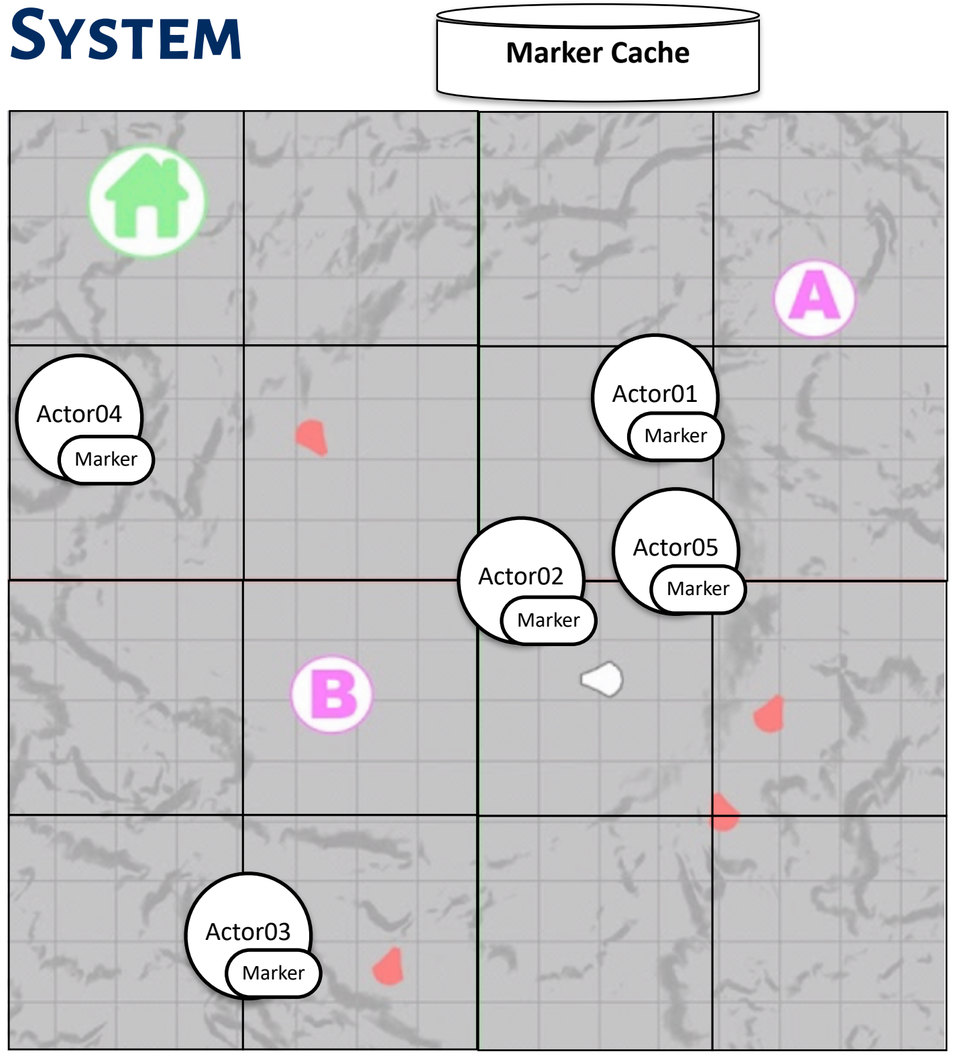

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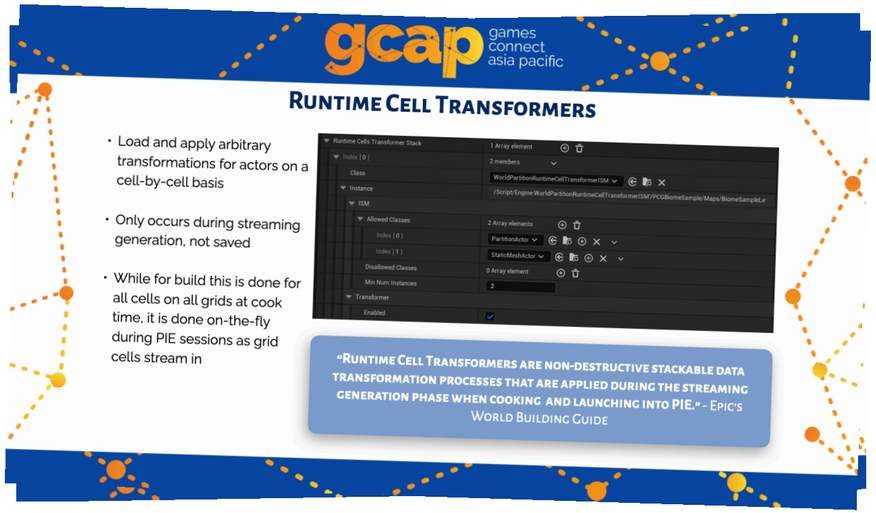

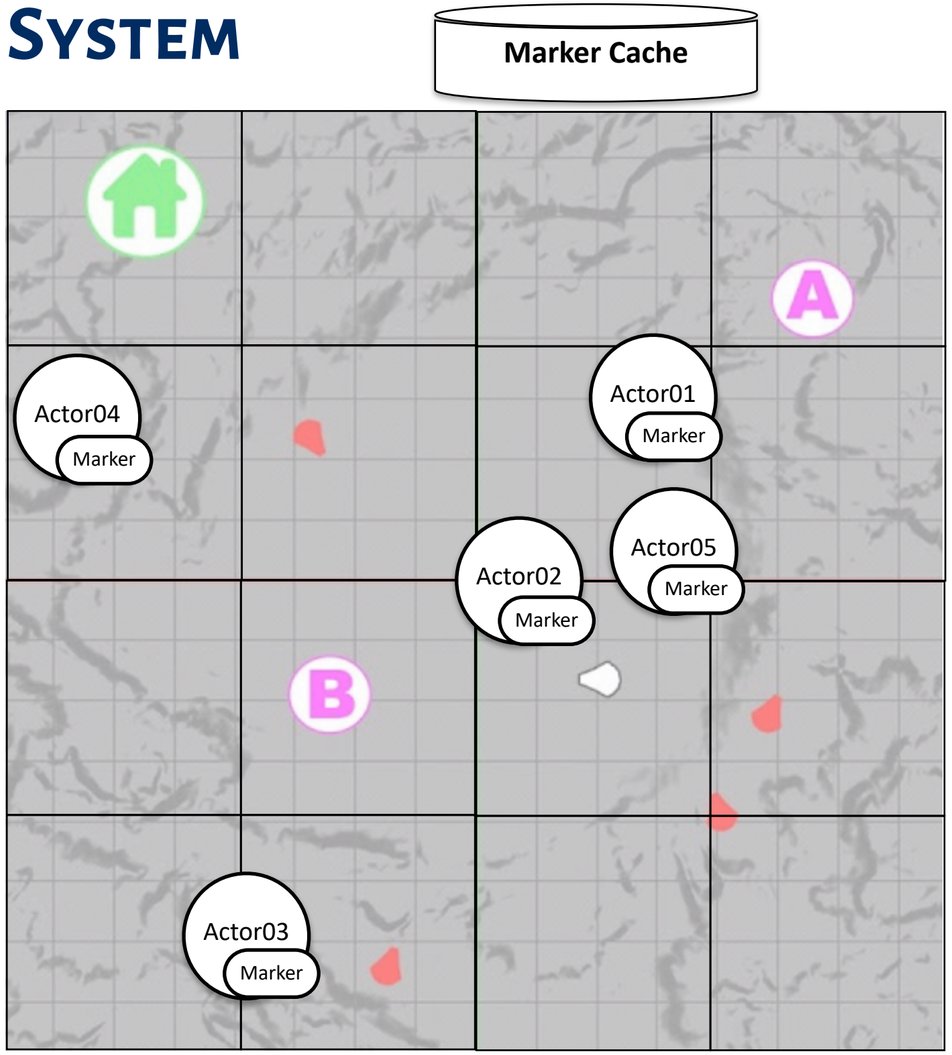

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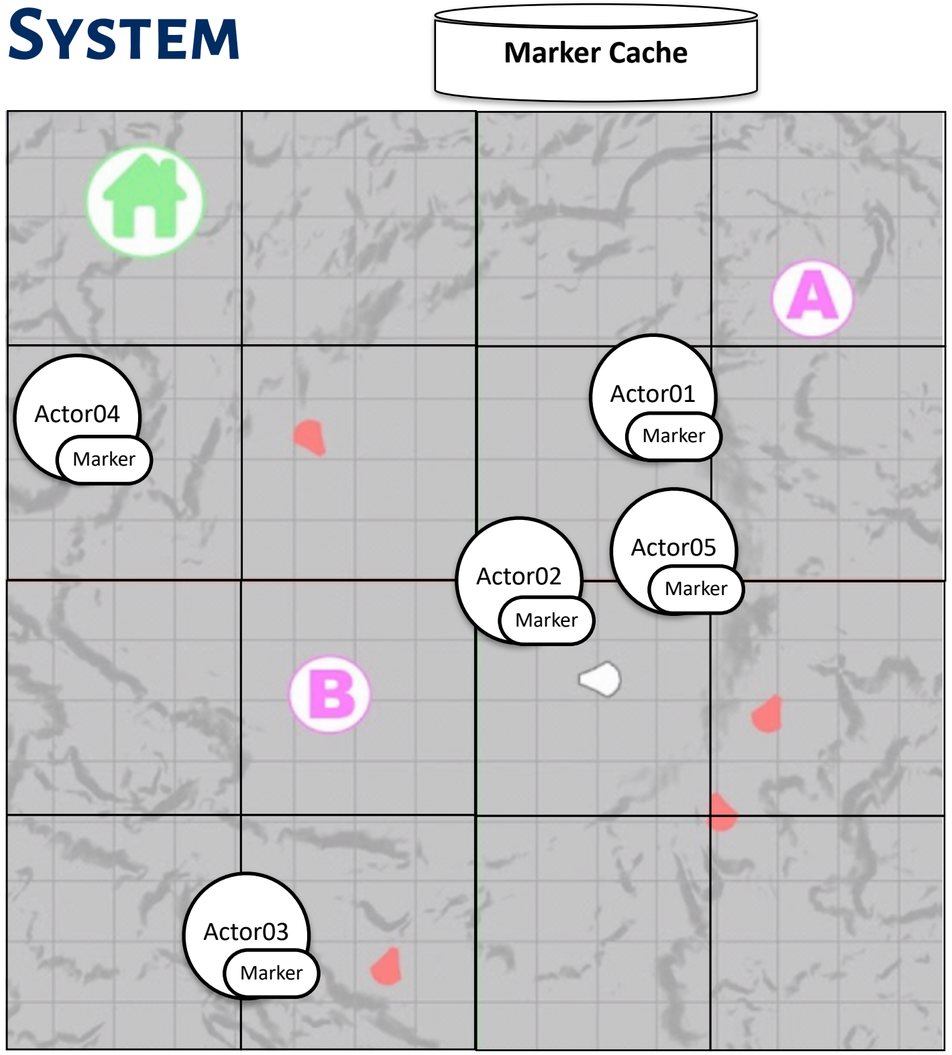

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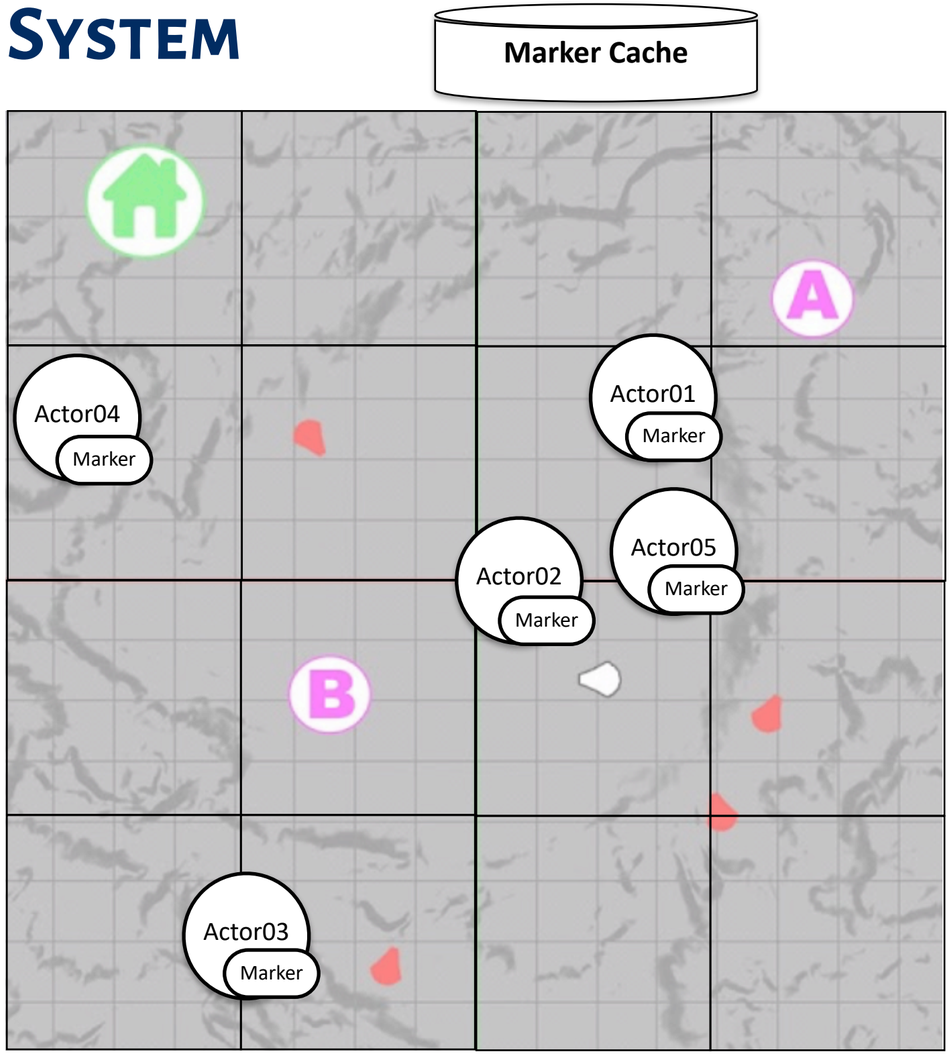

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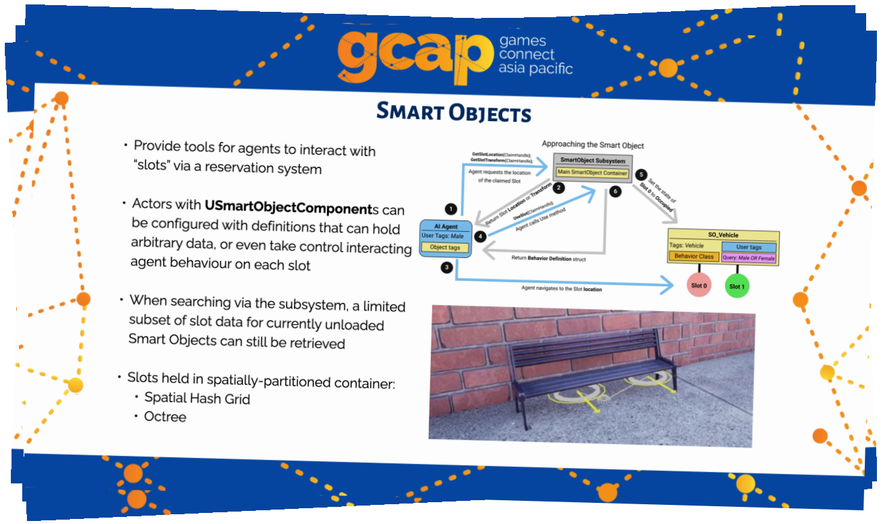

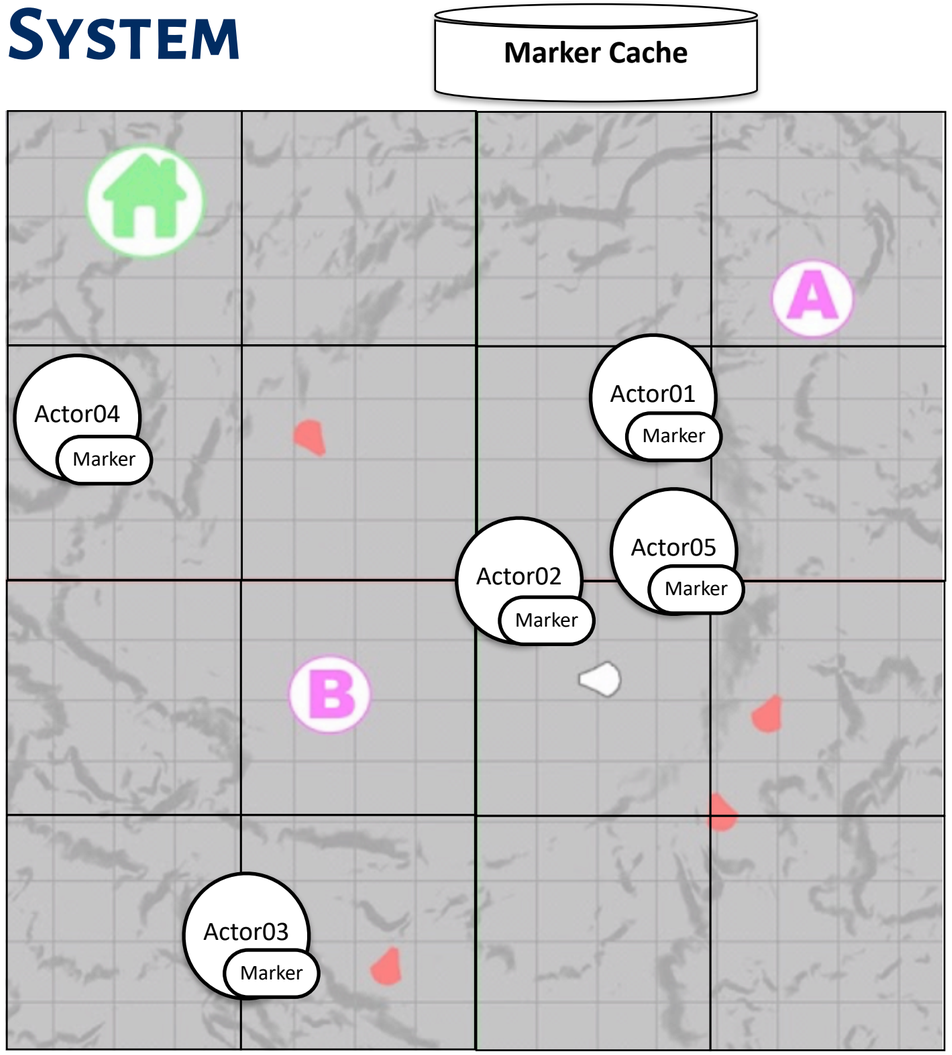

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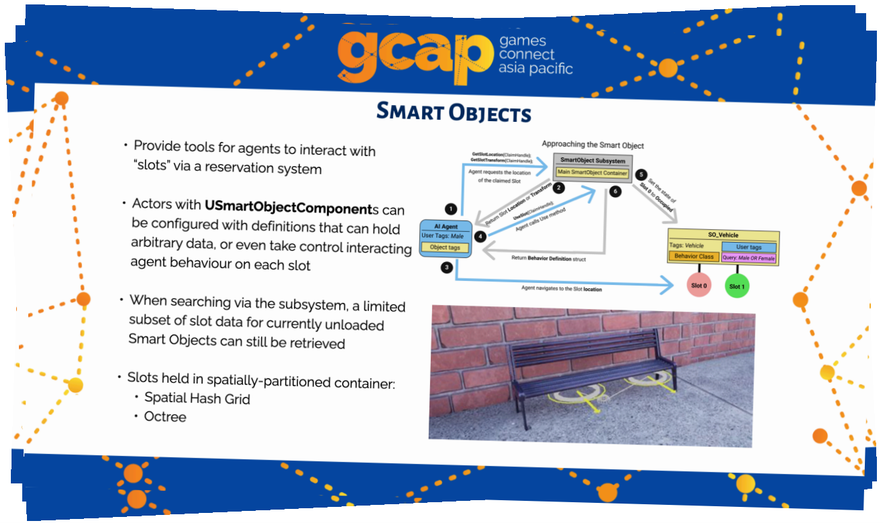

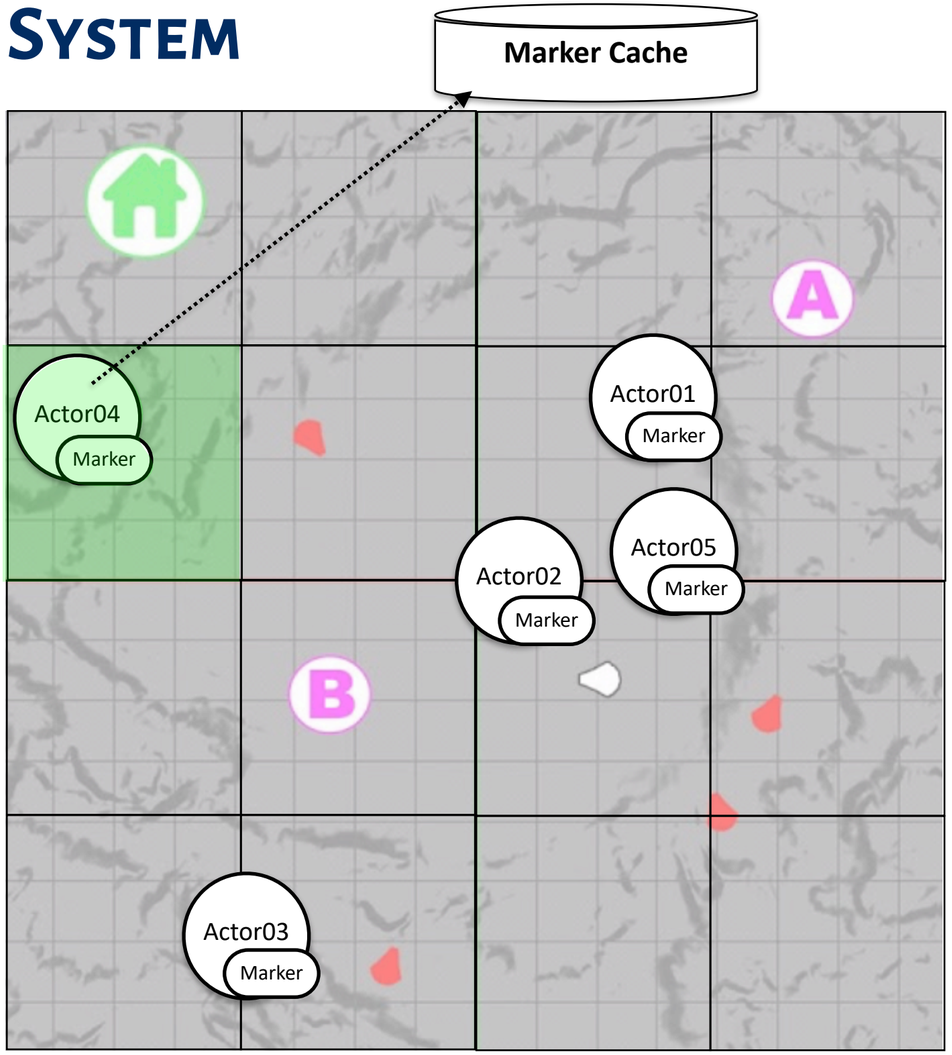

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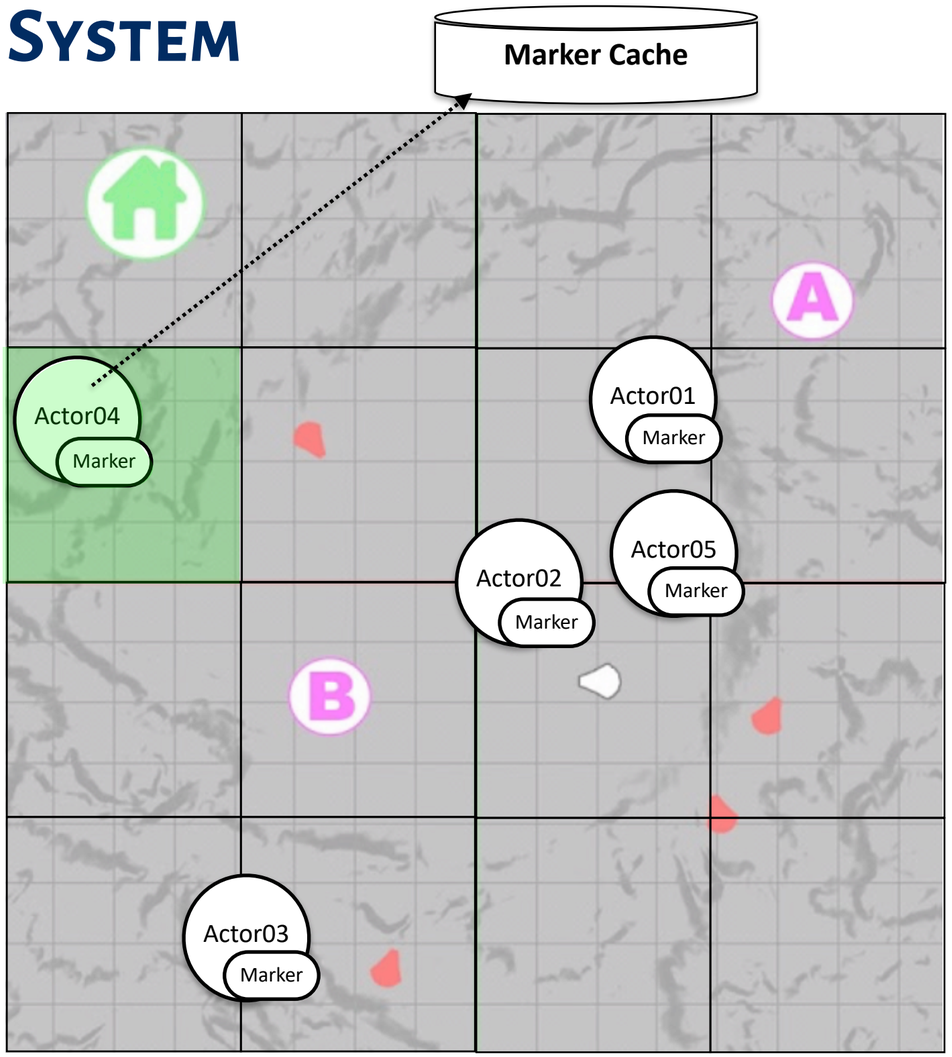

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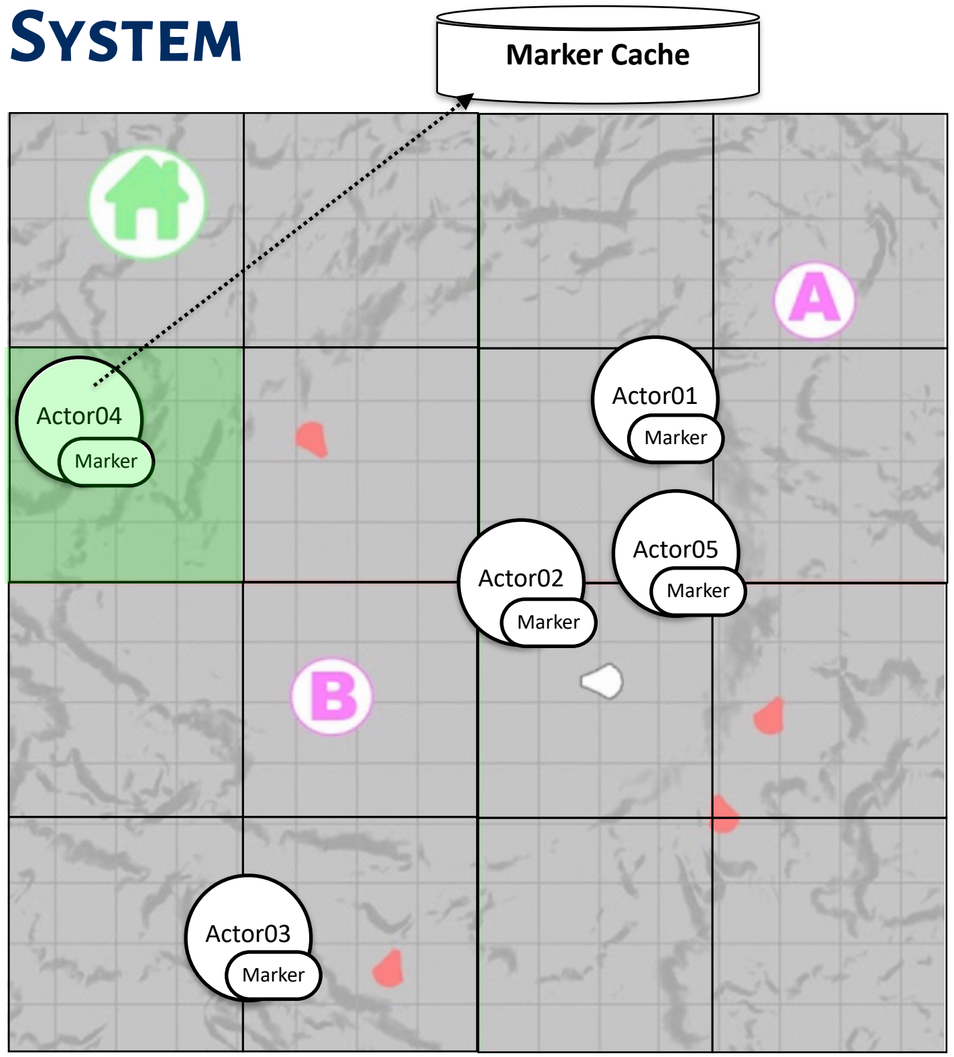

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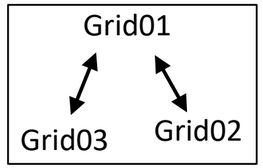

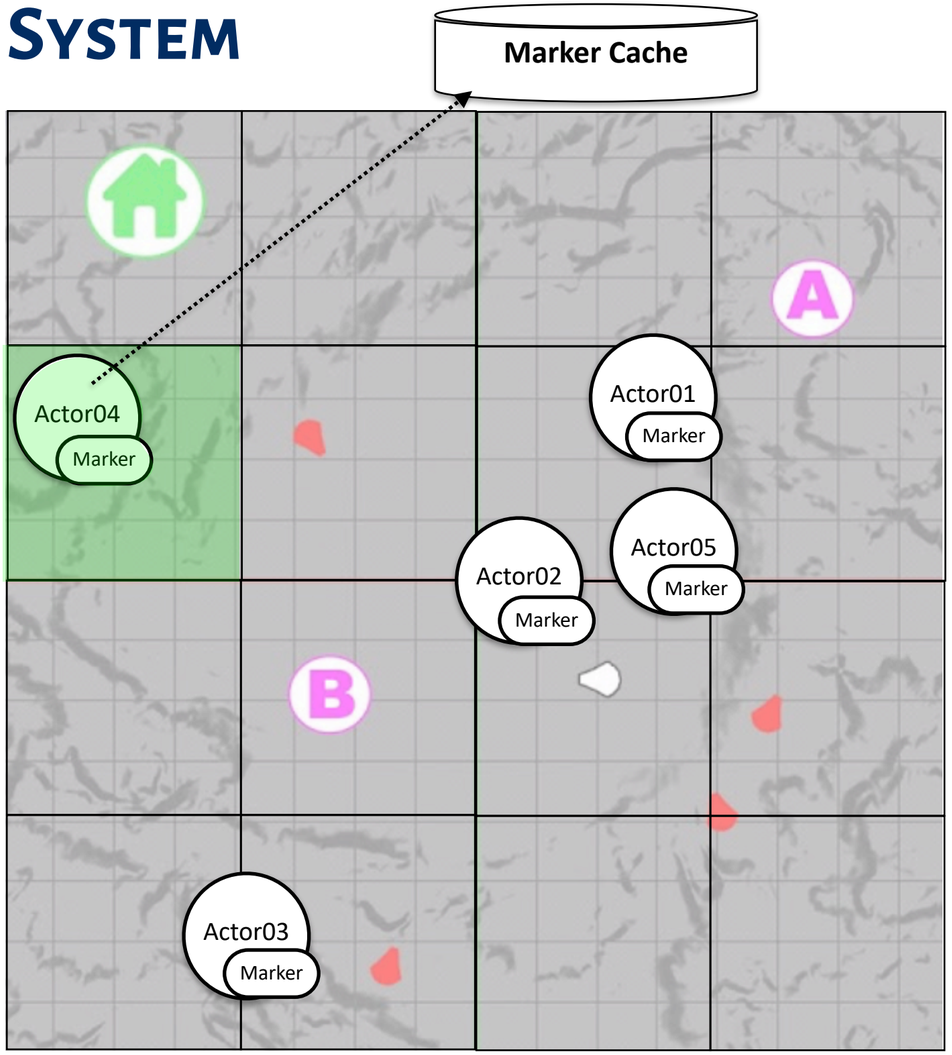

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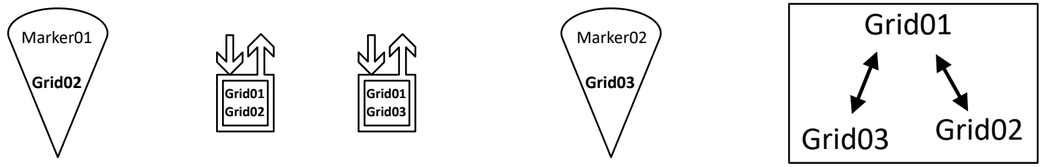

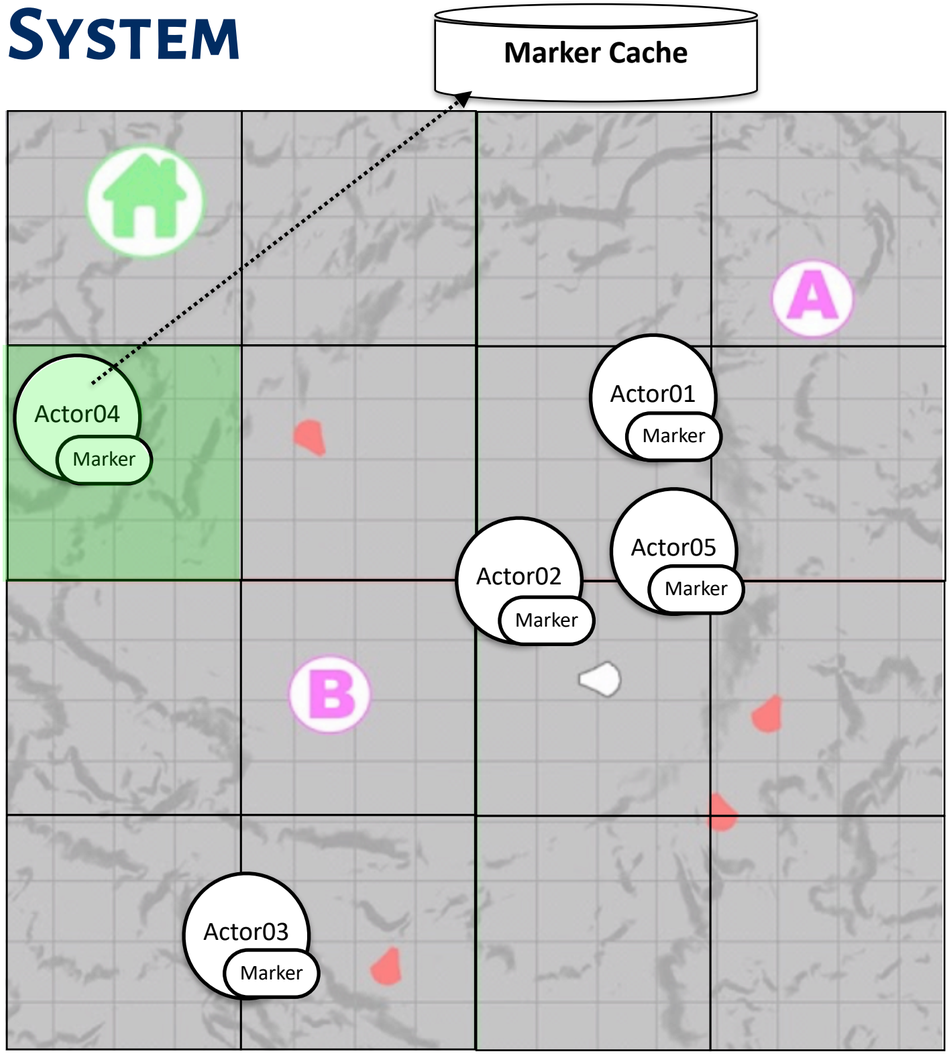

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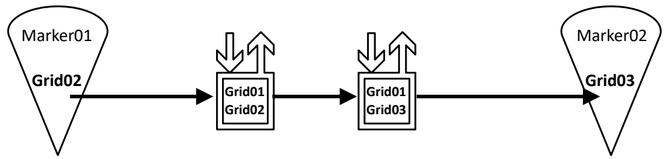
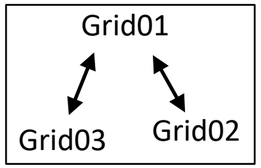
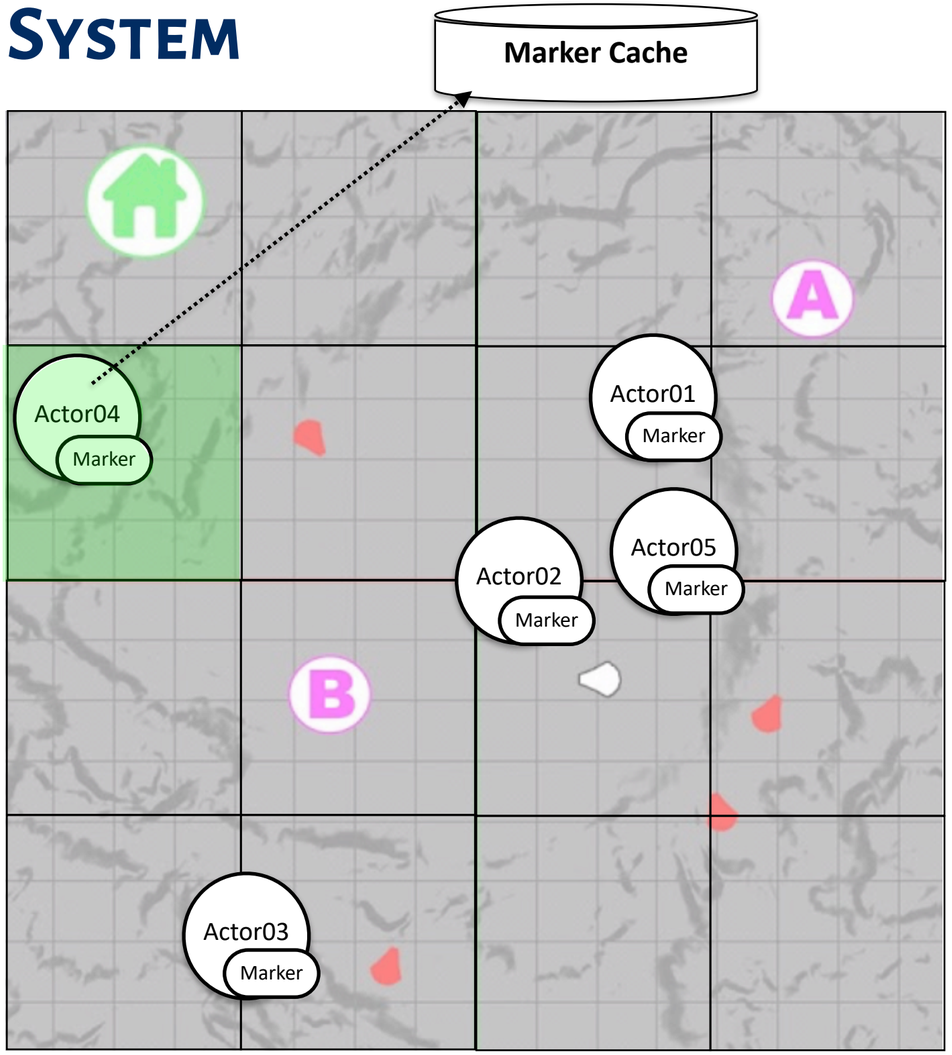


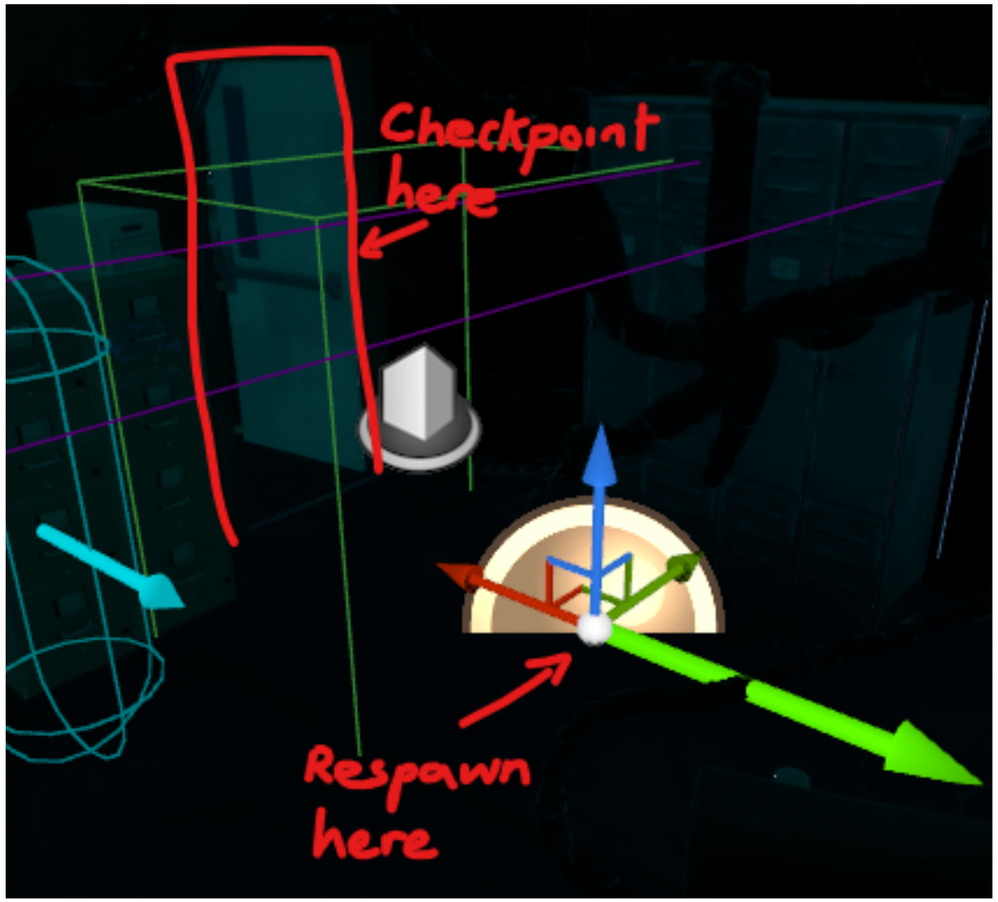




Serialisation Systems For Game State Persistence

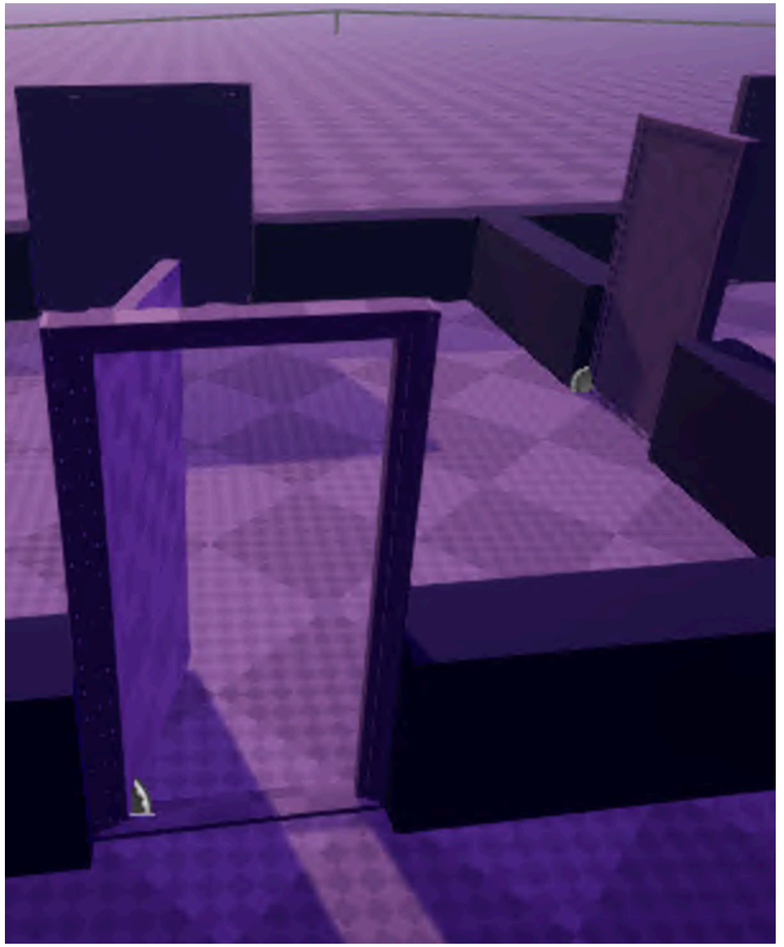
Condensing World & Streaming State Representation

- Author systems to operate on discreet states
  - Design actors to support reload scenarios
- Reduce states into tractable, configurable IDs
  - Avoid tying state data directly to assets
- Some state will be specific to actors in the world
  - Tag to save space and facilitate reset capabilities
- Allow save game data to be manually modified
  - Optional text-based serialisation can be useful for debugging and desk-checking game states
  - This functionality can work very well as a debug tool when allowing for state capture



Capturing Live State & Save Game Concerns

- Actors configure themselves on inference from world state
  - Avoids abusing Data Layers for minor details
- Taking in game state as a snapshot at any point is a relatively safe path assuming all critical triggers and state are serialised
  - Ensure save points and state change process is clear and controlled
- Ensure live capture cannot generate invalid game state
  - Reduce valid states where possible
- Managing world state conflicts is hard to do in an automated way, so good documentation on the effects of all quests over time is valuable

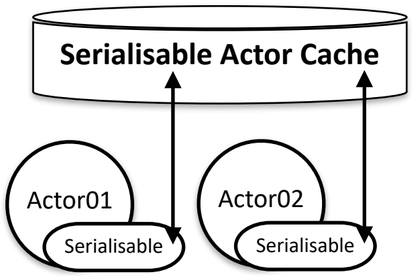


Intermediate State Caching

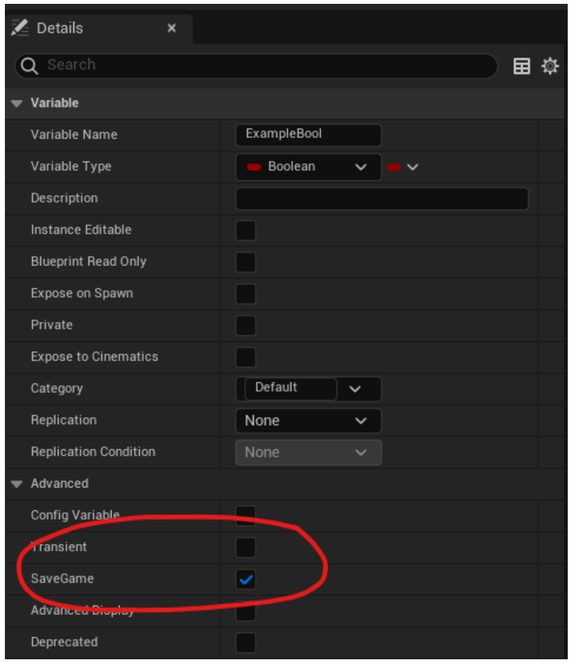
- Actors being streamed in and out need a way to restore critical state
  - It may also be important, depending on your game to be able to modify object states while unloaded

- The **USerialisableActorStateComponent** provides a simplified way defining these states
- Leverages **SerializeScriptProperties** with **SaveGame** - can be serialised out to an archive or variant

- Actors should be written to configure on changes coming from cache
- Unloaded lookup can be done based on the actor's SoftObjectPointer
- Special handling is needed for WorldPartitionSpawners
- Can be handled in batch




```
166
167  UCLASS(Blueprintable, meta = (BlueprintSpawnableComponent))
     1 derived blueprint class
168  class [redacted]UActorStateExampleComponent : public UActorComponent
169  {
170      GENERATED_BODY()
171
172  protected:
173
174      UPROPERTY(BlueprintReadWrite, SaveGame)
175      FVector ExampleVector = FVector::ZeroVector;  Unchanged in assets
176
177  };
178
```



Level Streaming Persistence Plugin

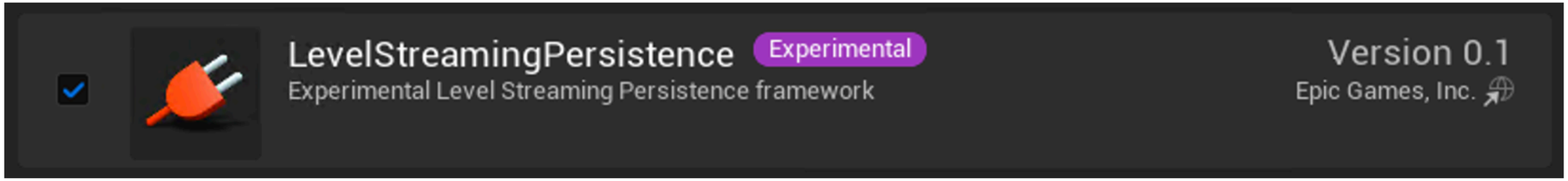
- Yup, Epic has a plugin for that…
- “Level Streaming Persistence” plugin is still experimental as of Unreal 5.6
- All persistent actor properties must be marked up in a config file with their full path
  - Can be brittle to path changes and renames
- Does not handle replacement of actor destroyed state
- Provides ability to remotely modify properties marked “public”

Level Streaming Persistence (Experimental)

JEAN-SEBASTIEN GUAY | Posted on April 2023

Level Streaming Persistence is a plugin that manages saving and restoration of specific marked properties on objects contained within a streamed-out/in Level. These properties are defined within the engine configuration (ini) file.

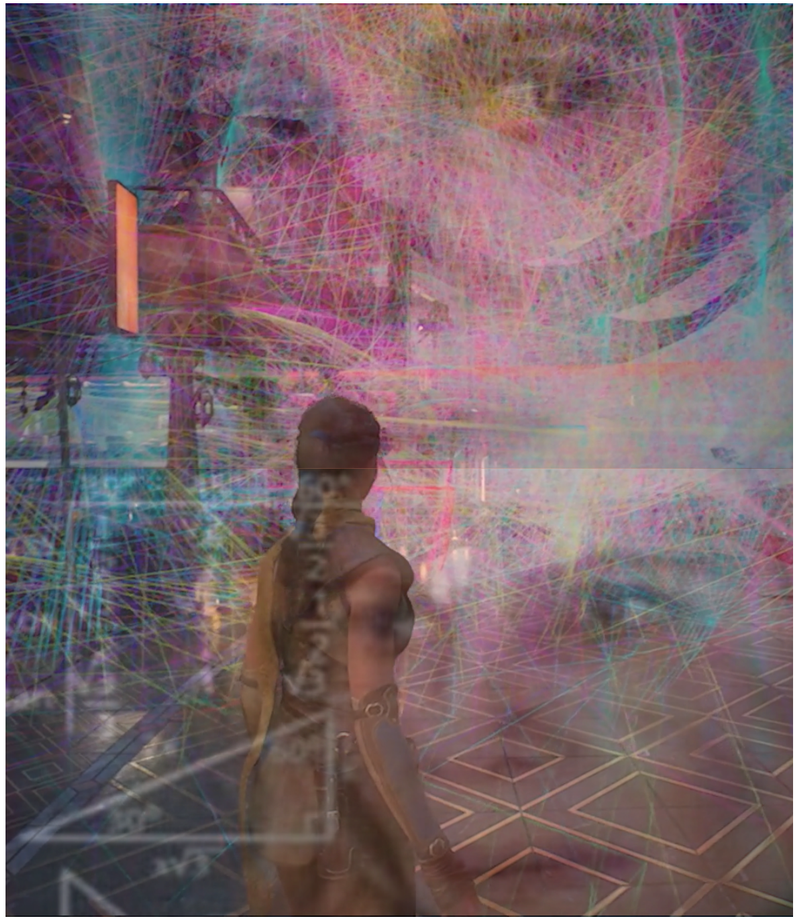
This provides persistence of properties during gameplay from the in-memory snapshot, as well as across sessions, if implemented through the provided API.



Wrap-up, Summary And Q&A

Summing it all up

- World Partition is a very deep bag of tools enabling parallel workflow, level streaming, and actor/geometry optimisation
- Be aware of the tooling and dimensionality you have available, and intentionally plan out its usage ahead of time
- Managing open world state can become quite complex - it's valuable to build in assumptions, and limit possibility space
- Approach all systems and features with a plan for persistence early and evaluate impact of streaming on all functionality



Q&A

Thanks for watching!

Slides Available Here For Download

JonJonDev.com/documents/GCAP25StreamingAndSerialisation.pdf

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