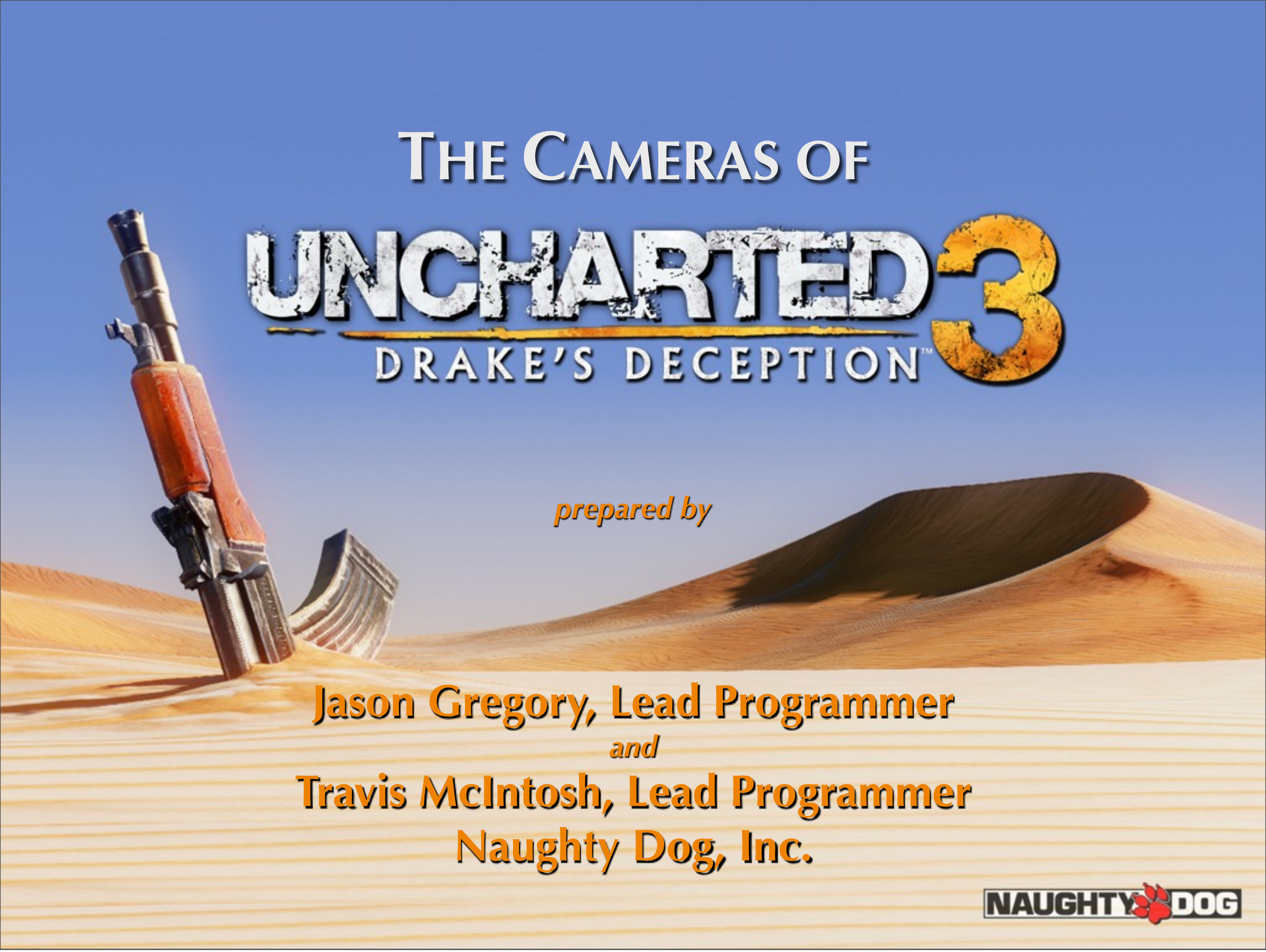
The Cameras of



prepared by

Jason Gregory, Lead Programmer

and

Travis McIntosh, Lead Programmer

Naughty Dog, Inc.

Agenda

- Overview
- The Render Camera
- Game Cameras
- Blending and the Camera Stack
- The Camera Manager
- Follow Camera
- Camera Collision
- Aim Camera
- Melee Camera
- Camera Additives
- 3D
- Future Directions

UNCHARTED 3 DRAKE'S DECEPTION

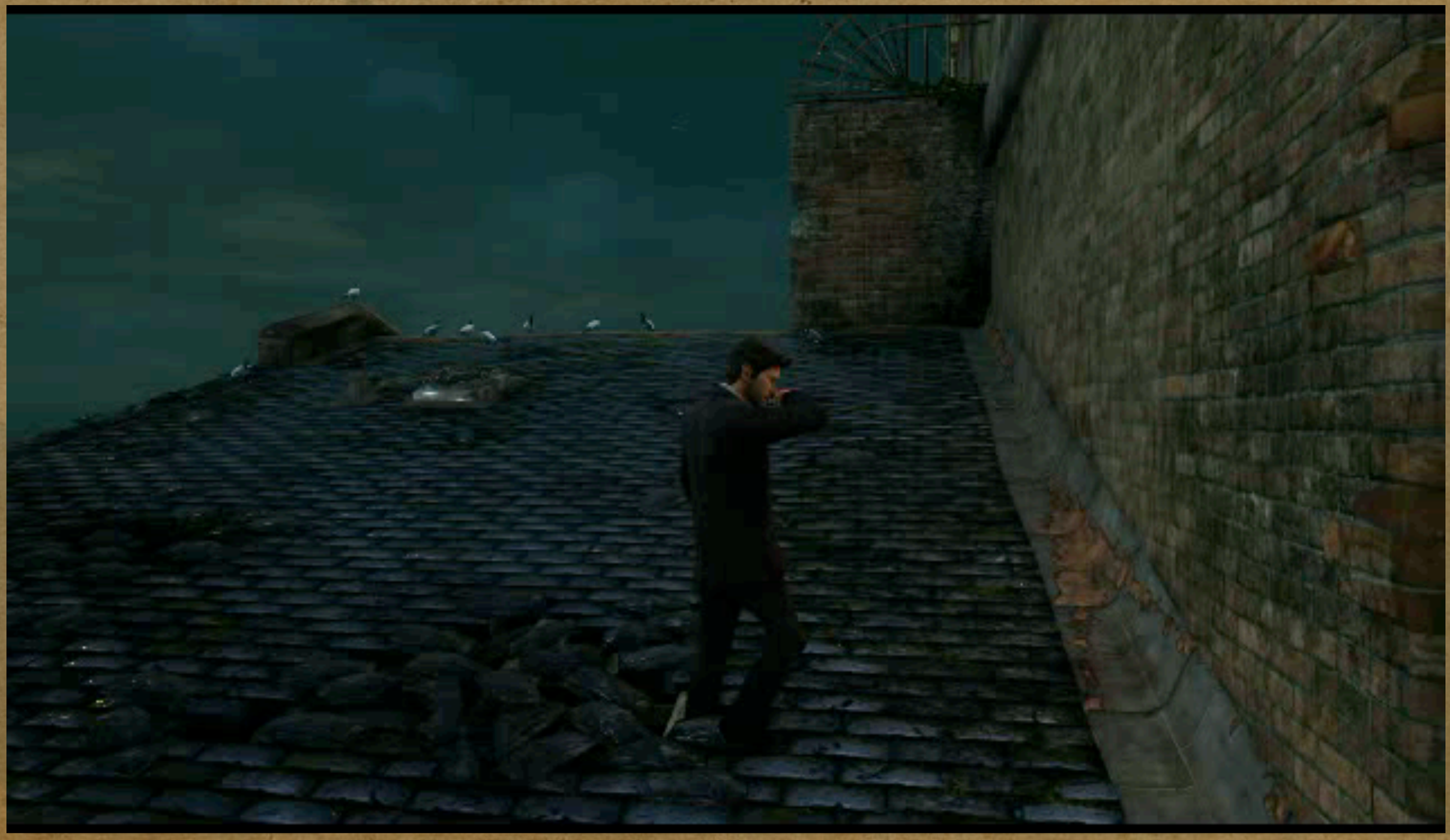
NAUGHTY DOG

Overview

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Overview



UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Overview

- **Duties** of typical game camera system:
  - **Approximate model** of real-world camera
  - Control position, orientation, zoom, depth-of-field, other parameters **over time**
  - Support various **camera types** (behaviors)
  - Manage **cross-blends** between cameras
  - Detect and resolve **collisions**

The Render Camera

- Low-level **interface** to **rendering engine**
  - Parameters include:
    - position, orientation, aspect ratio, field of view (FOV), frustum clip planes, projection properties (ortho, perspective), 3D parameters (e.g. interocular distance)
- **One** render camera for **full-screen**
  - **One** render camera for **3D** (rendered twice, offset left and right for each eye)
  - **Two** render cameras for **split-screen**

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Game Cameras

- Render camera API inconvenient for game programmers and designers
- **Game camera** abstraction more useful
  - C++ **class** = distinct camera **behavior**
  - C++ **instance** = **logical camera** in world
  - Blending between instances = cross-fade between camera **locations**, **settings** and/or **behaviors**

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Game Cameras

- **31 camera types** in *Uncharted 3*
  - Evolved extensively over the series
  - We'll explore a handful of these today
- Three categories:
  - Code-driven cameras
  - Designer-controlled cameras
  - Debug cameras

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Code-Driven Cameras

- Follow camera
- Edge camera
- Aim camera
- Cover camera
- Melee camera
- *etc.*

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Designer-Controlled Cameras

- Examples:
  - Fixed camera
  - Pivot camera
  - Spline camera
  - Animated camera
  - *etc.*
- Cameras placed in level editor (Charter) and activated via script
- Designers can also override settings of code-driven cameras

Debug Cameras

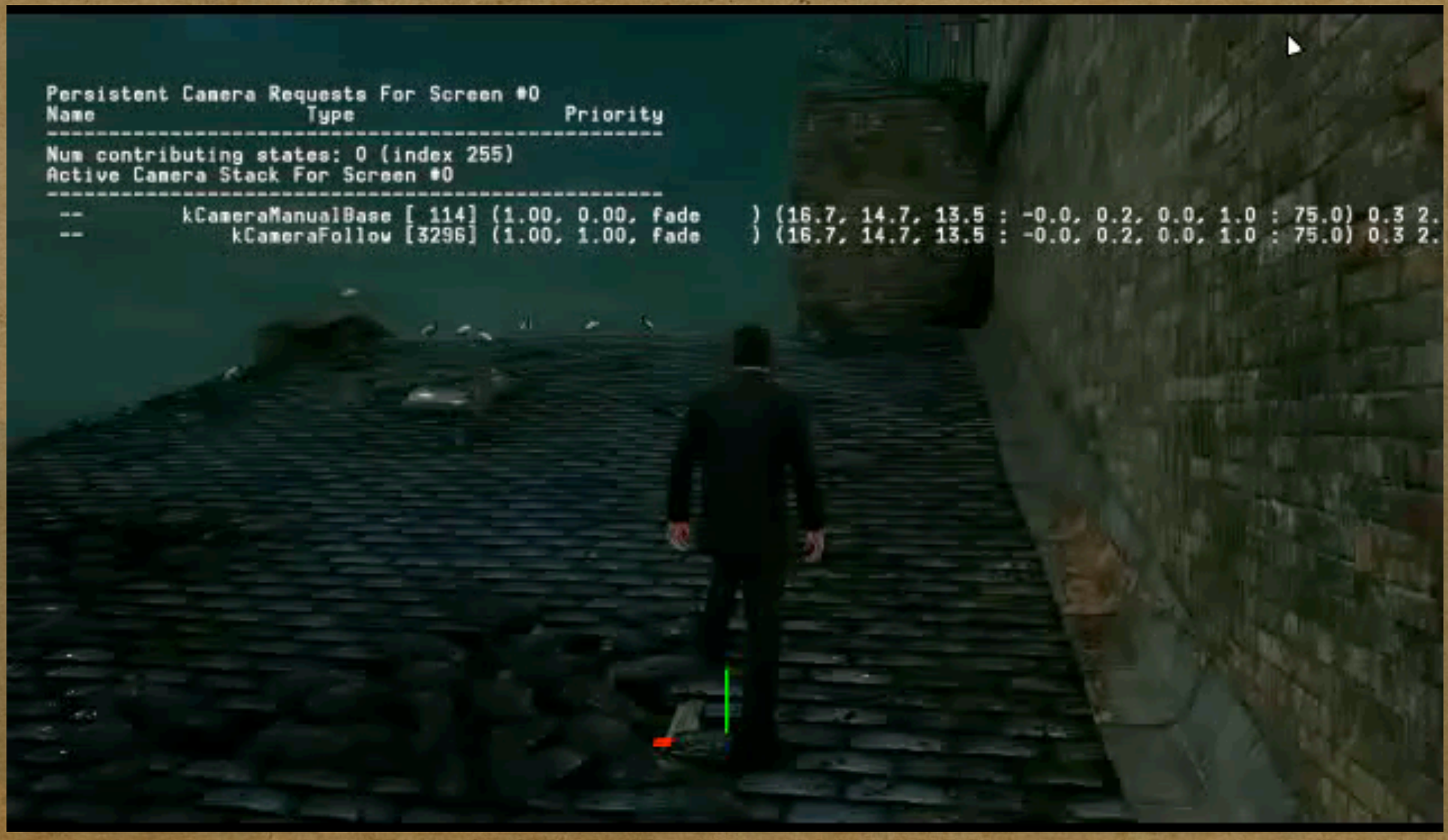
- Free-flying camera
- Simple “no clip” follow camera
- Stick camera (simple follow cam)

Game Cameras

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Game Cameras



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Blending and the Camera Stack

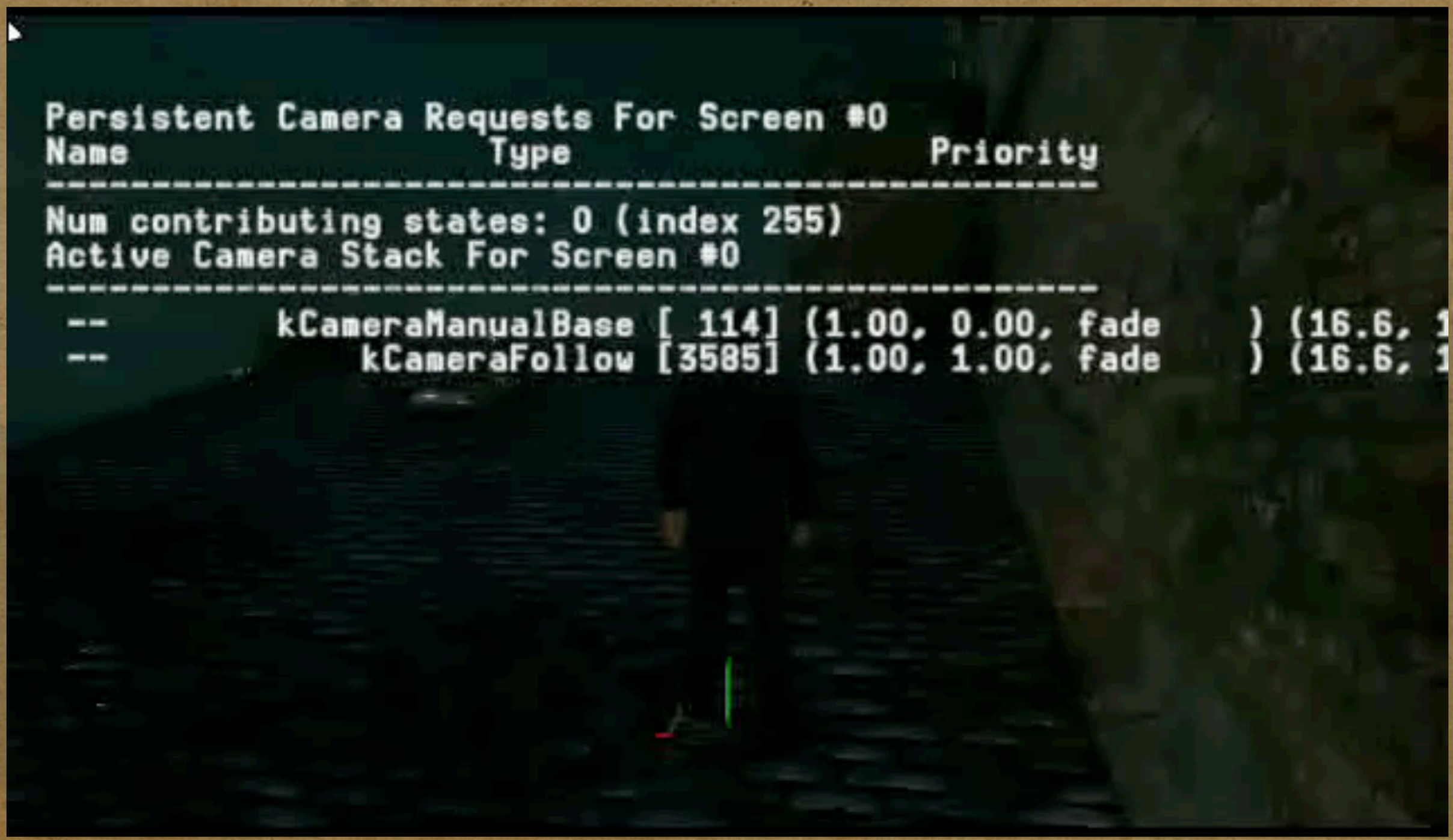
- Cross-fading between cameras implemented using a simple stack
  - Each new camera is pushed onto the stack
  - Fades up from 0.0 to 1.0 (100%) over time
  - Blended with camera(s) below it on stack
  - Implicit contribution of non-top cameras is $(1 - \beta)$, where β is contribution of top camera
  - Once a camera is no longer contributing, it is automatically removed from the stack

Blending and the Camera Stack

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Blending and the Camera Stack



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Camera Manager

- **Simultaneous camera requests** are resolved by the camera manager
- Simple **priority-based** system:
  1. Most **code-driven** cameras (follow, edge, cover) have lowest priority
  2. **Designer-specified** cameras are next
  3. **Special code-driven** cameras (aim, death) have highest priority

Camera Manager

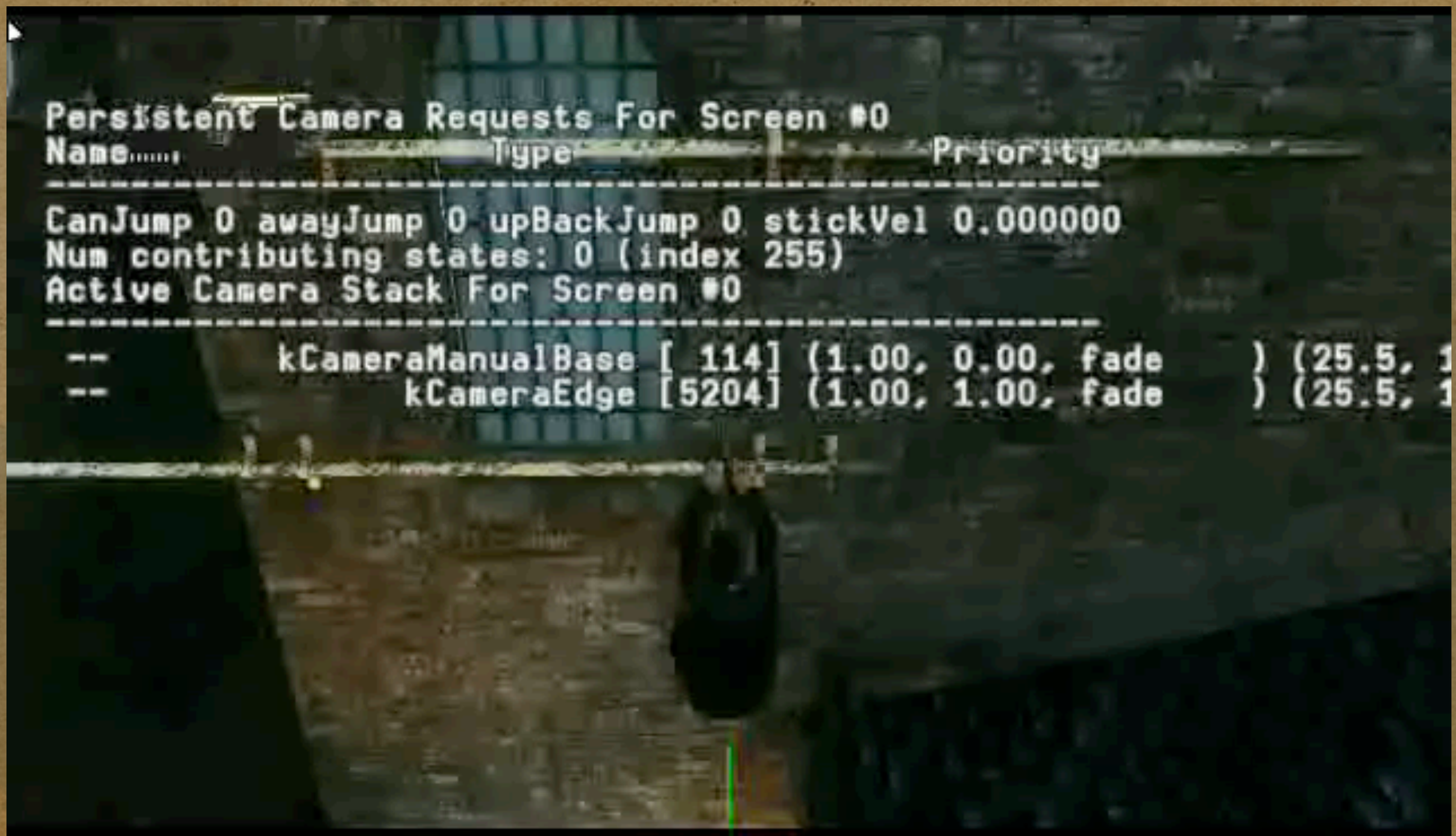
- **Code-driven** cameras requested **every frame**
- **Designer** cameras requested only **periodically** (via script)
- Therefore designer camera requests are maintained on a **persistent list**
- Every frame, camera manager:
  - finds highest-priority designer request (if any)
  - compares to highest-priority code-driven request
  - highest priority of these two “wins”
- Designers can **disable** or **abandon** their camera requests in script

Camera Manager

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Camera Manager



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Fixed Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Fixed Camera

UNCHARTED 3 DRAKE'S DECEPTION

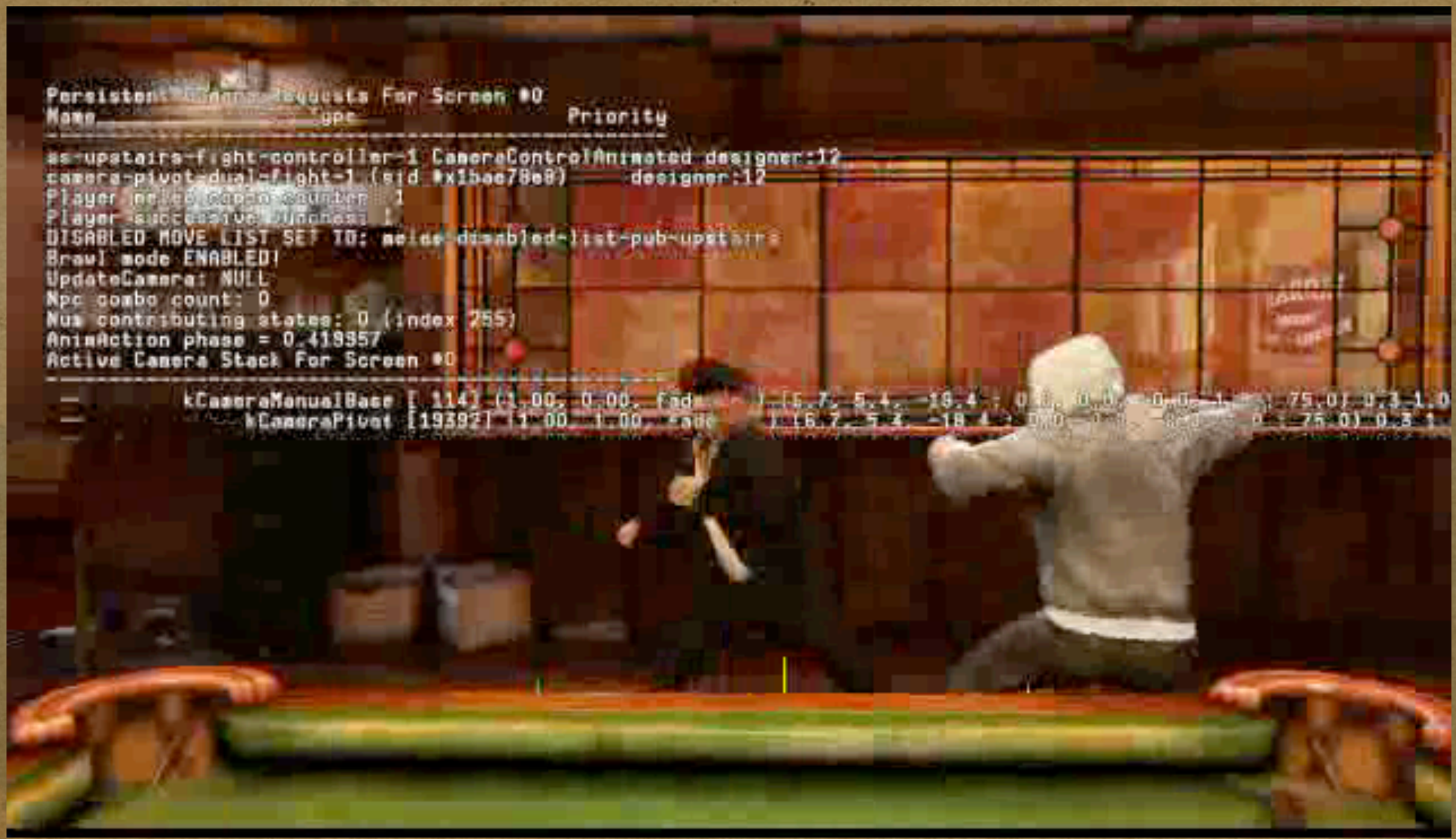
NAUGHTY DOG

Pivot Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Pivot Camera



UNCHARTED 3 DRAKE'S DECEPTION

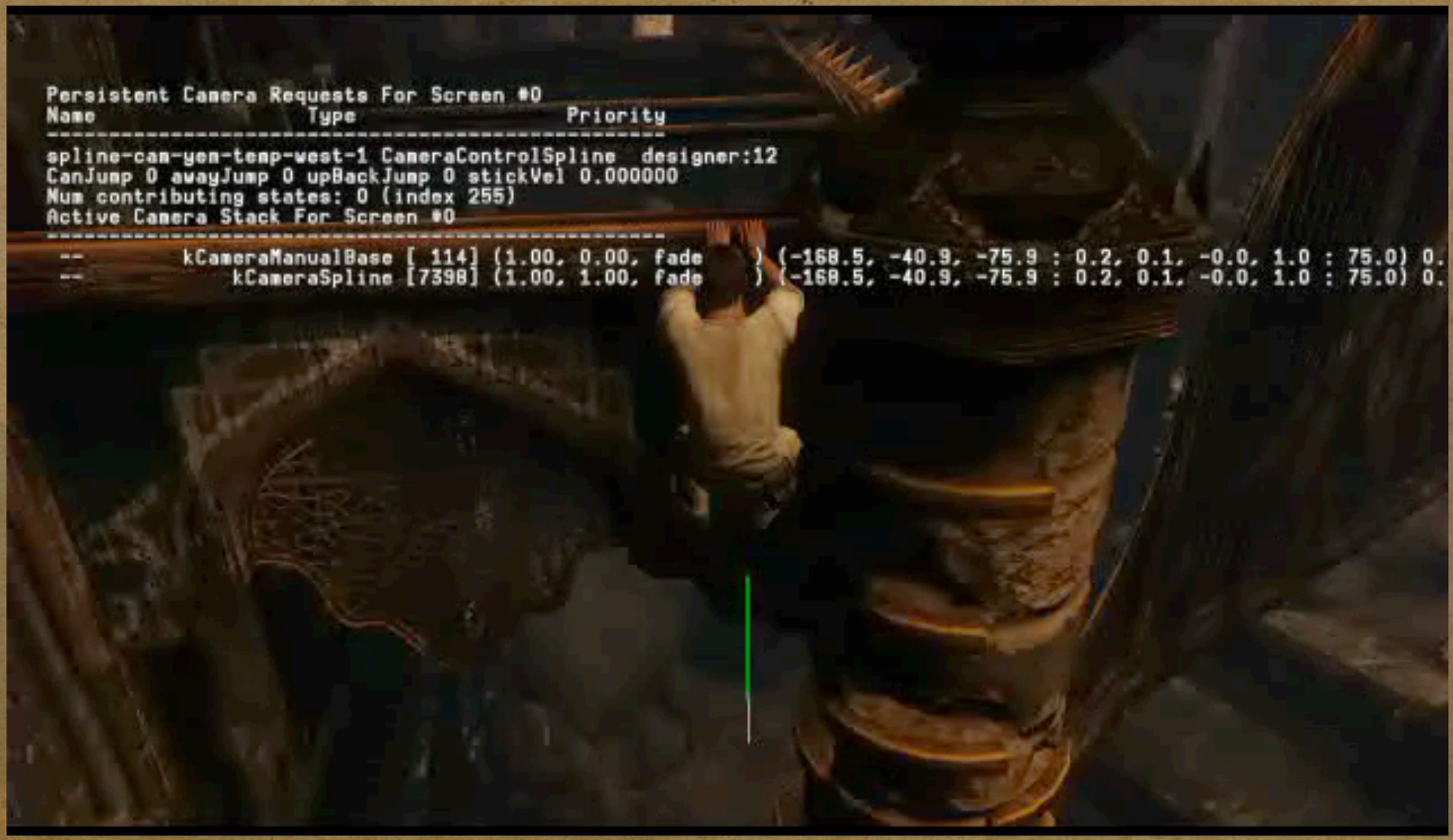
NAUGHTY DOG

Spline Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Spline Camera



UNCHARTED 3 DRAKE'S DECEPTION

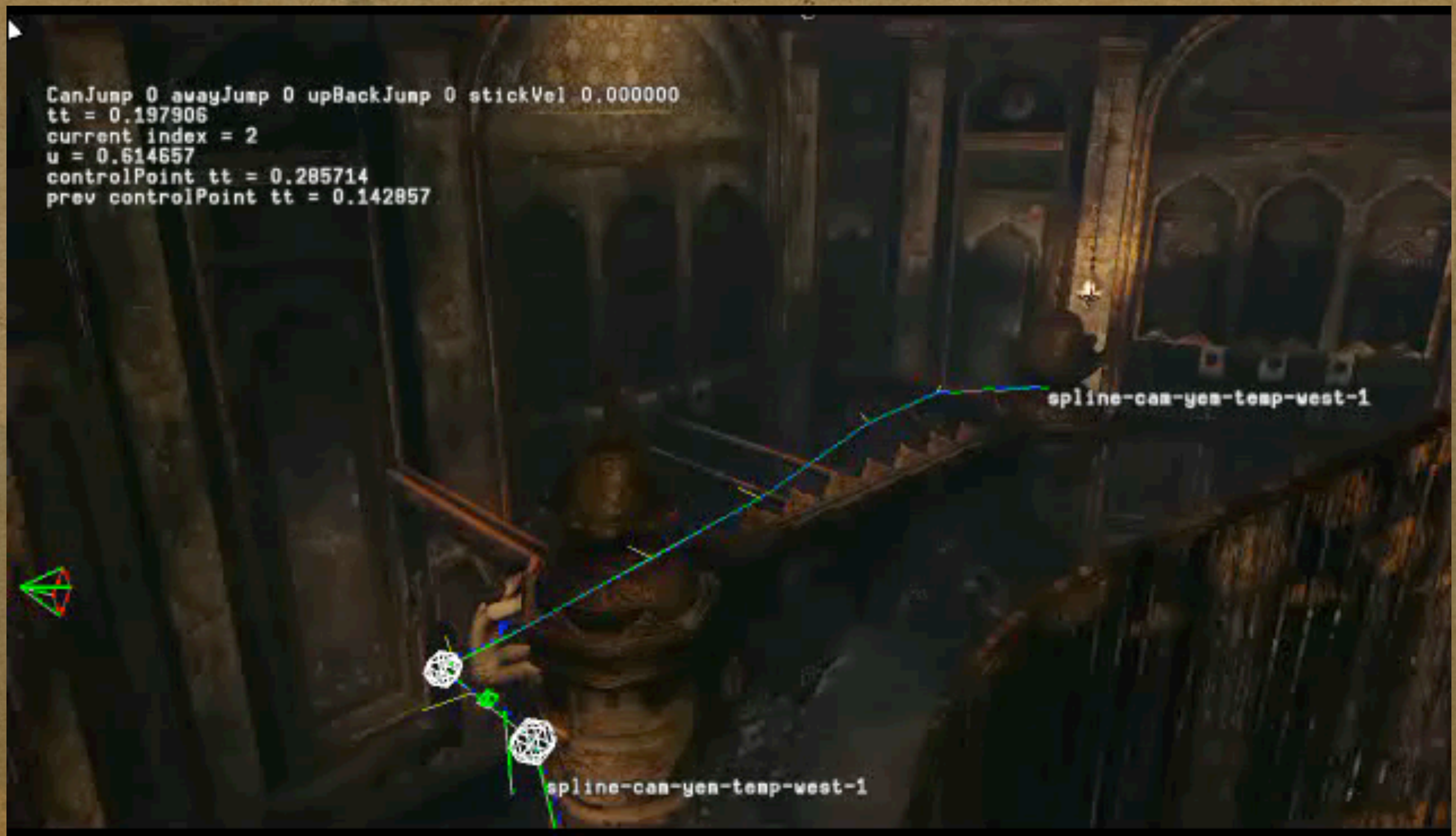
NAUGHTY DOG

Spline Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Spline Camera



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Debug Cameras

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Debug Cameras

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Blending Debug Cameras

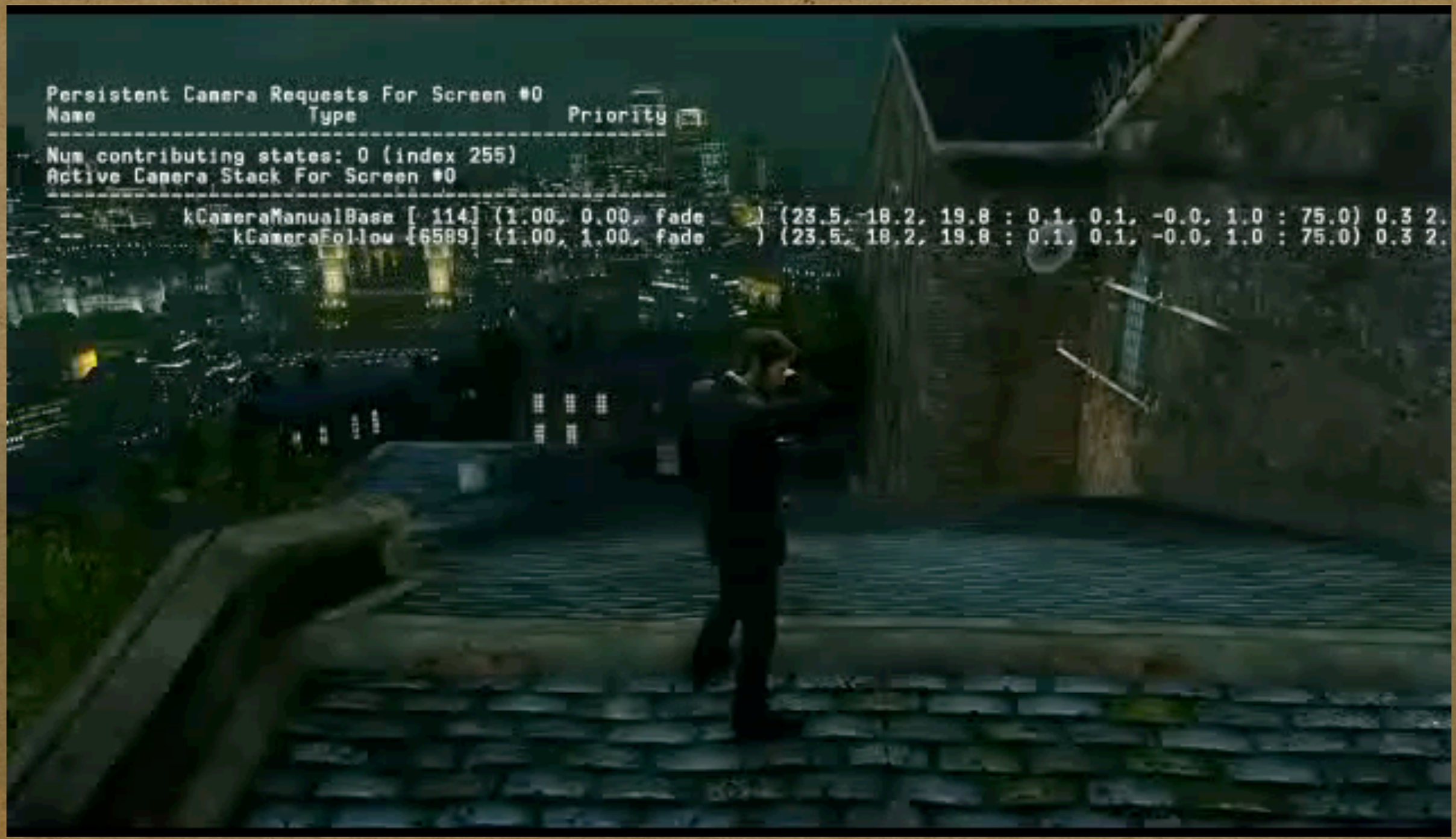
- Debug cameras are handled in a special way on the camera stack:
  - The debug fly camera **masks** the cameras below it on the stack, rather than **blending** with them
  - All cameras below the debug fly cam are **oblivious** to its presence on the stack, and therefore **never blend out**
- Also, we keep a second debug fly camera at the **very bottom** of the stack, as a safeguard in case all other cameras get popped

Blending Debug Cameras

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Blending Debug Cameras



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera

- More than 50% of player's time spent in the **follow camera**
- Most difficult camera type to get right
  - **Target point** is controlled by game (follows the player)
  - **Orientation** is player-controlled (right stick)
  - But camera can also **auto-rotate** to follow player (in some situations)
  - Excellent **collision resolution** is crucial (and very tricky!)

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera

- Simple **horizontal** rotation about player
- **Vertical** rotation controlled by two **splines**:
  - target point spline
  - camera position spline
- Splines can be **edited in-game**

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Collision

- Two fans of **sphere casts** (horizontal and vertical)
- Re-position and/or re-orient camera based on which direction has **most free space**

Follow Camera: Collision

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Collision

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Modes

- Two rotation modes
- In **traversal**...
  - auto-rotate to follow player
- In **combat**...
  - **never rotate the camera**, because this would interfere with player's targeting

Follow Camera: Traversal

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Traversal

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Combat

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Follow Camera: Smoothing

- Ideal post-collision camera position **jitters** quite a lot
  - we **smooth** this with a simple spring
- **Spring-mass** system in a **viscous fluid**:
  - $m\,(d^2x/dt^2) + c\,(dx/dt) + k^2x = 0$
  - **Critically damped** to prevent oscillation
  - Solution: $(A + Bt)e^{-kt}$
- Spring generally much tighter in combat than in traversal mode

Designer-Overridden Settings

- Designers can control **follow camera settings** via script, to tailor behavior for specific areas in the game world
- Can also control **preferred angle** of follow camera
- Useful at conclusion of **in-game cinematic**,
- or to direct player's attention toward a **point of interest**

UNCHARTED 3 DRAKE'S DECEPTION

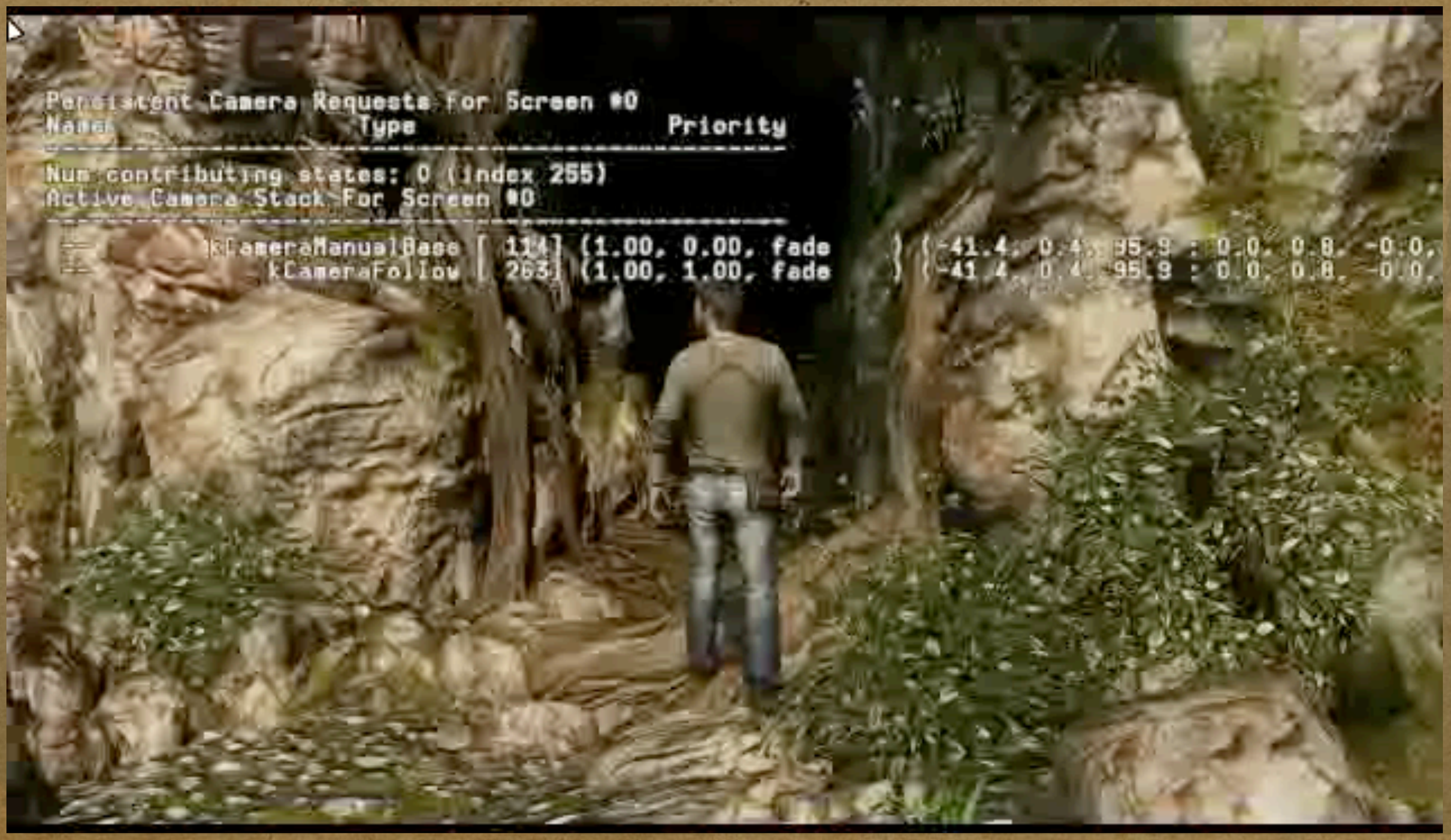
NAUGHTY DOG

Designer-Overridden Settings

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Designer-Overridden Settings



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Aim Camera

- Requirements:
  - Resolve collisions without changing **aim angle**
  - Maintain **center of screen** when blending back and forth with other camera types

Aim Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Aim Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Aim Camera: Collision

- Collision done via a few simple **sphere casts**
- Camera position interpolates between:
  - **ideal "far"** camera position, and
  - a **secondary "close"** camera position

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Aim Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Aim Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Animated Cameras

- When procedural cameras won't cut it, **animators** can control the camera directly
- In Maya, special locators called **action pack references** (apReferences) are used to export custom animations
- An apRef can be **constrained** to a **Maya camera**, allowing the camera's movements to be exported to the game

Animated Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Animated Camera

UNCHARTED 3
DRAKE'S DECEPTION

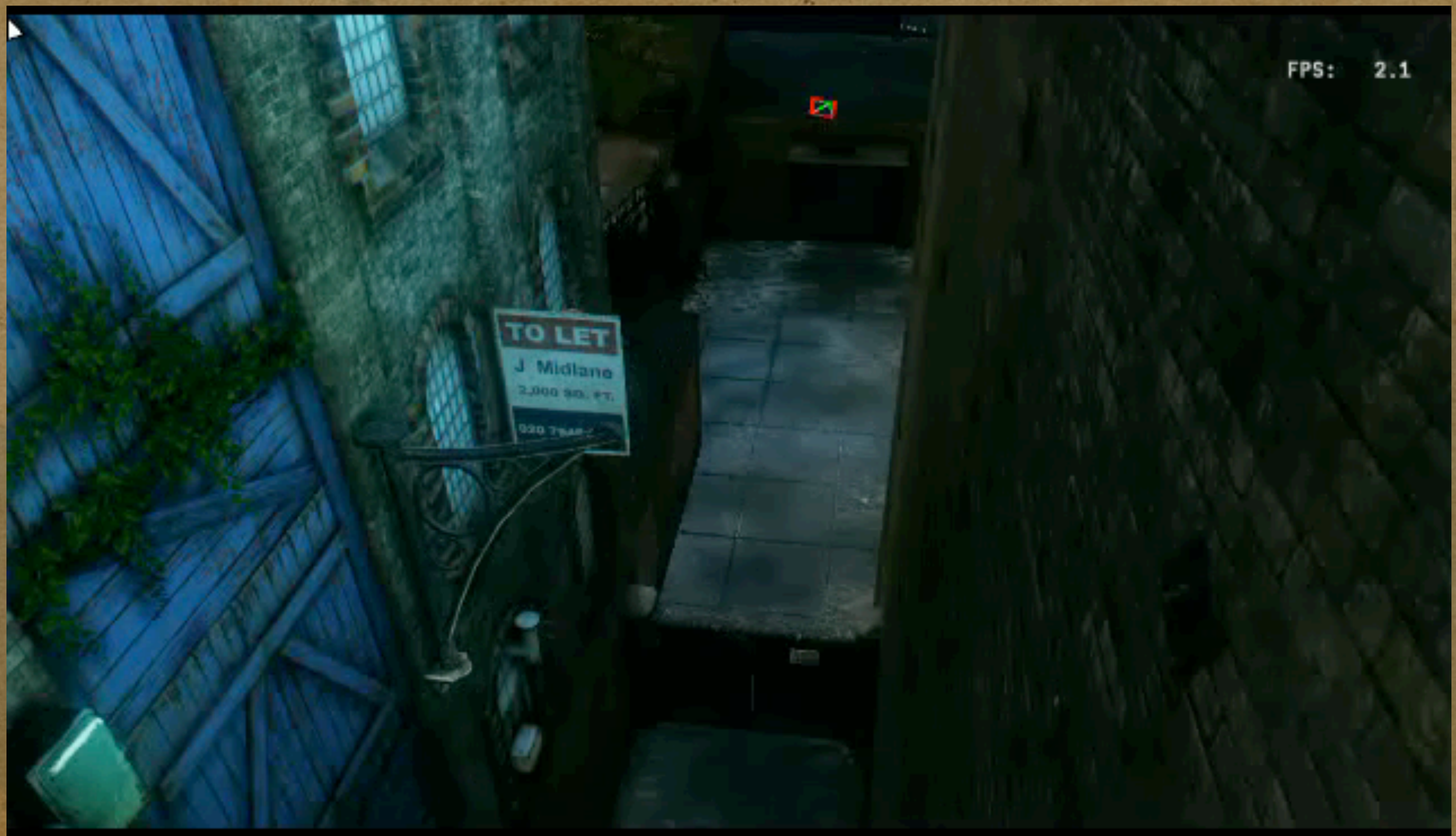
NAUGHTY DOG

Animated Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Animated Camera



UNCHARTED 3
DRAKE'S DECEPTION

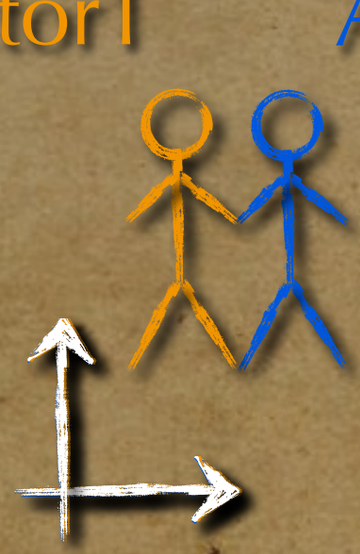
NAUGHTY DOG

ApRef as Common Reference

- An apRef can also be used to provide a **common point of reference** between the various actors in a scene

ApRef as Common Reference

- An apRef can also be used to provide a **common point of reference** between the various actors in a scene



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Animated Melee Camera

- Animated cameras are used in **melee**
- Multiple **camera paths** are authored for each melee move
- At run time, **ray casts** filter out any animated camera paths that would **collide** with game world:
  - select an animated path if possible,
  - else fall back to procedural melee cam

UNCHARTED 3 DRAKE'S DECEPTION

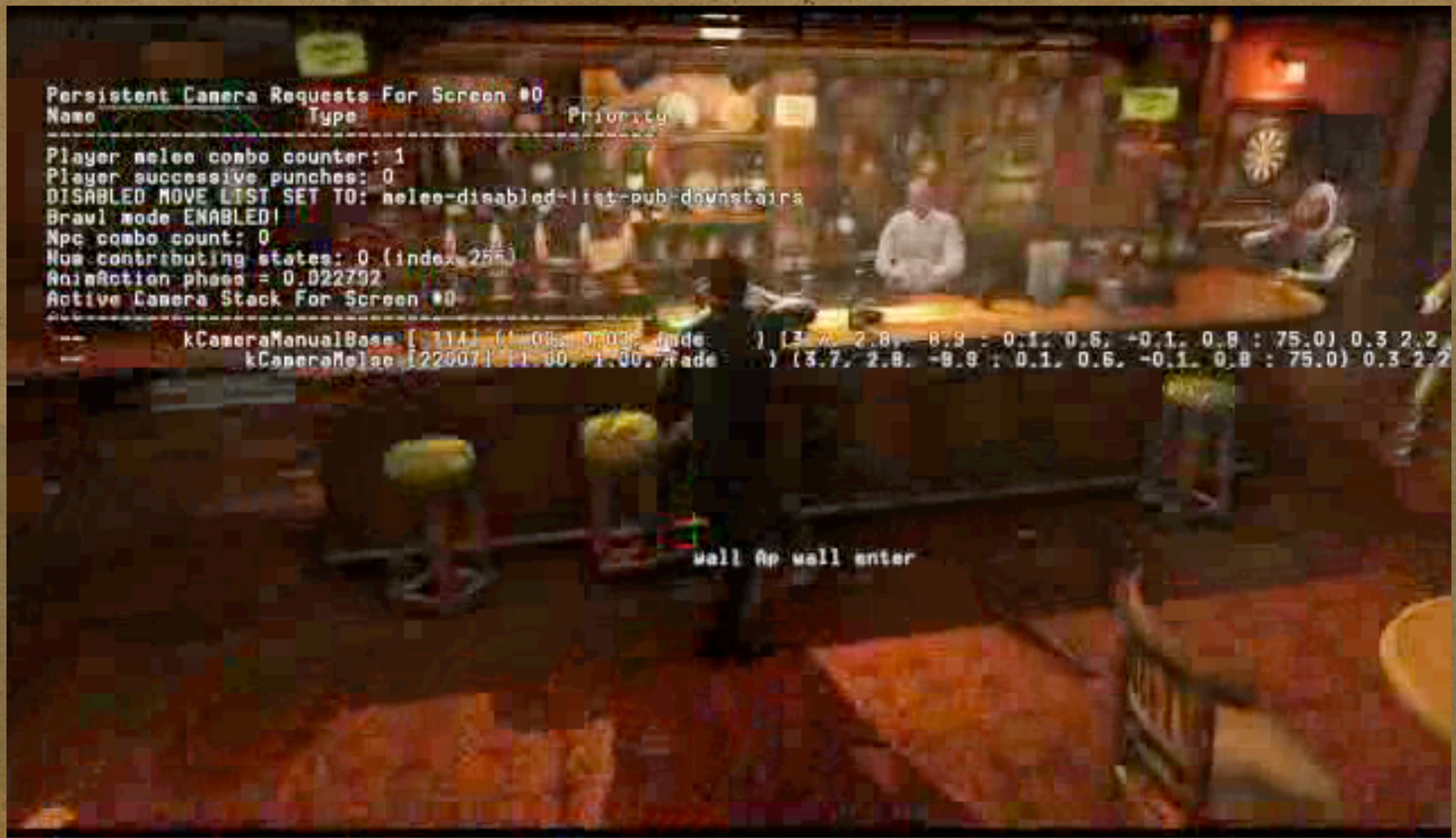
NAUGHTY DOG

Animated Melee Camera

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

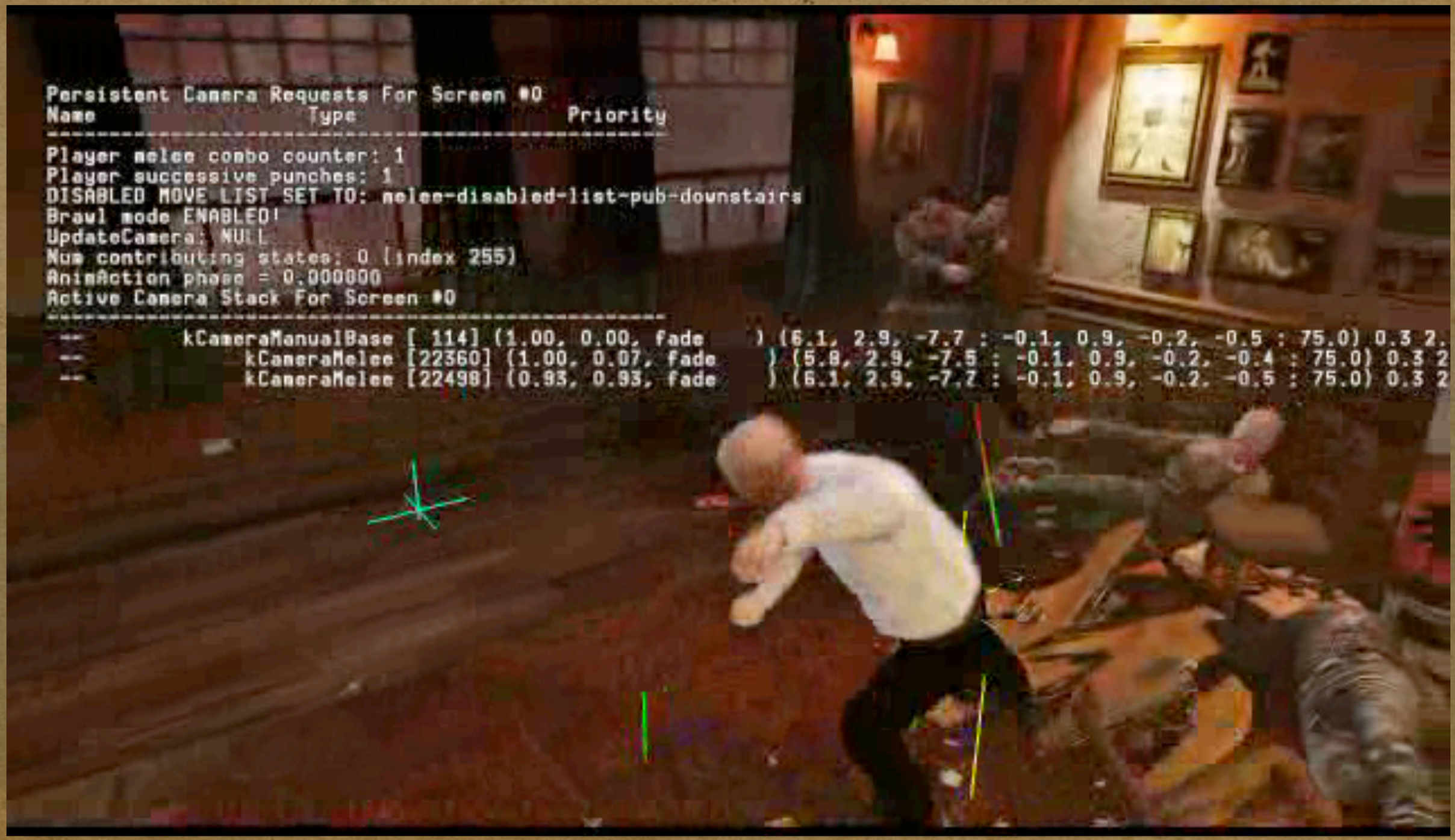
Animated Melee Camera



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

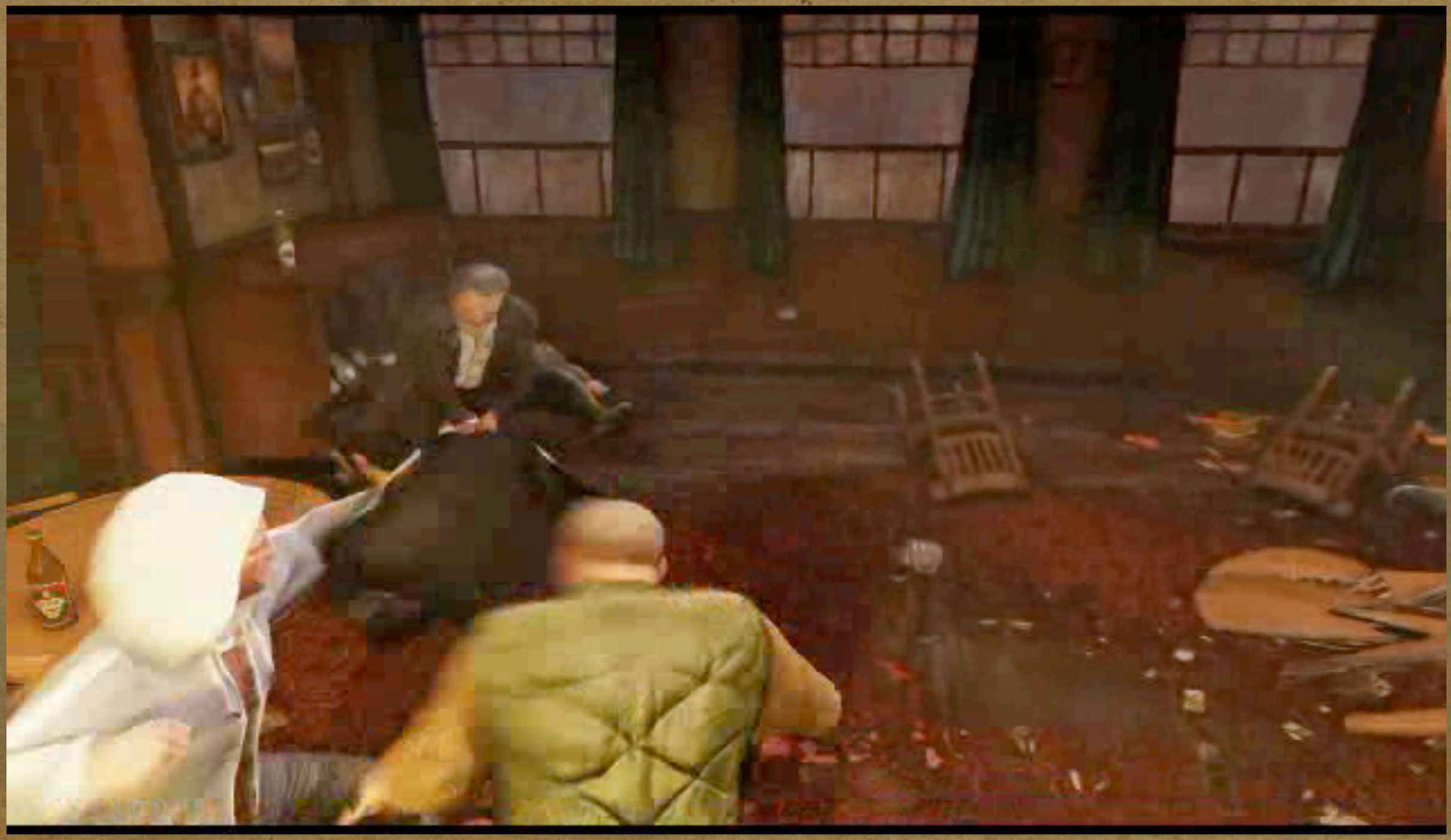
Animated Melee Camera



UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Animated Melee Camera



UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Camera Additives

- Animator-authored camera "shake" effects implemented using **additive** animations
  - Authored as a "regular" camera animation in Maya
  - Applied as translational and rotational **deltas** at runtime
  - Therefore a given additive shake can be applied **virtually anywhere** in-game

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Camera Additives

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG

Camera Additives

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Camera Additives

- Very effective when used **carefully**
- Useful for **small** camera movements only
  - **Low-frequency** and small movements “read” well to most players
  - High-frequency or large movements are too easily misinterpreted as **frame-rate hitches** or **camera bugs**
  - Applied ***after*** **camera collision**, so large movements can also put camera back into collision!

Stereoscopic 3D

- 3D effect achieved by **offsetting** the primary render camera left and right, and re-rendering the scene for **each eye**
- **Inter-ocular distance** controls relative parallax differential between the eyes
- Player can configure this in the options menu
- Kept fixed throughout the game

Stereoscopic 3D

- **Zero-plane distance** represents the plane in 3D space at which the eyes converge
  - i.e. where objects will appear to coincide with the physical TV screen
  - In *U3*, we generally never wanted objects to “pop out” of the screen — all 3D effects go “into” the screen
  - Zero-plane distance **automatically** adjusted, by reading the depth buffer, to guarantee no “pop out”

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Future Work

- Camera collision currently done on a per-camera basis
  - This means collision detection/resolution is imperfect during cross-fades
  - Would like to add a final collision “clean up” pass — perhaps single sphere cast from camera to target
- Would like better camera pre-vis tools
- Maintaining screen center when blending between cameras is currently done on a per-camera basis
  - Would like a general solver framework, so new cameras could be added easily without having to rewrite the screen center maintenance code for each one

UNCHARTED 3 DRAKE'S DECEPTION

NAUGHTY DOG

Workshop

Please join me in the workshop session
immediately following this talk
for further discussion and Q&A

jason_gregory@naughtydog.com

UNCHARTED 3
DRAKE'S DECEPTION

NAUGHTY DOG