GDC 12

Effects Techniques Used in Uncharted 3: Drake's Deception

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Monday, March 12, 12

Good afternoon, and welcome to my talk on the effects techniques used in Uncharted 3: Drake's Deception. My name is Marshall Robin, I'm a visual effects programmer at Naughty Dog. I've been at Naughty Dog since 2005, and I've been working on the Uncharted series since Drake's Fortune.

Overview

- Goals for effects system
- Tools
- Runtime
- Example - Sand Footprints

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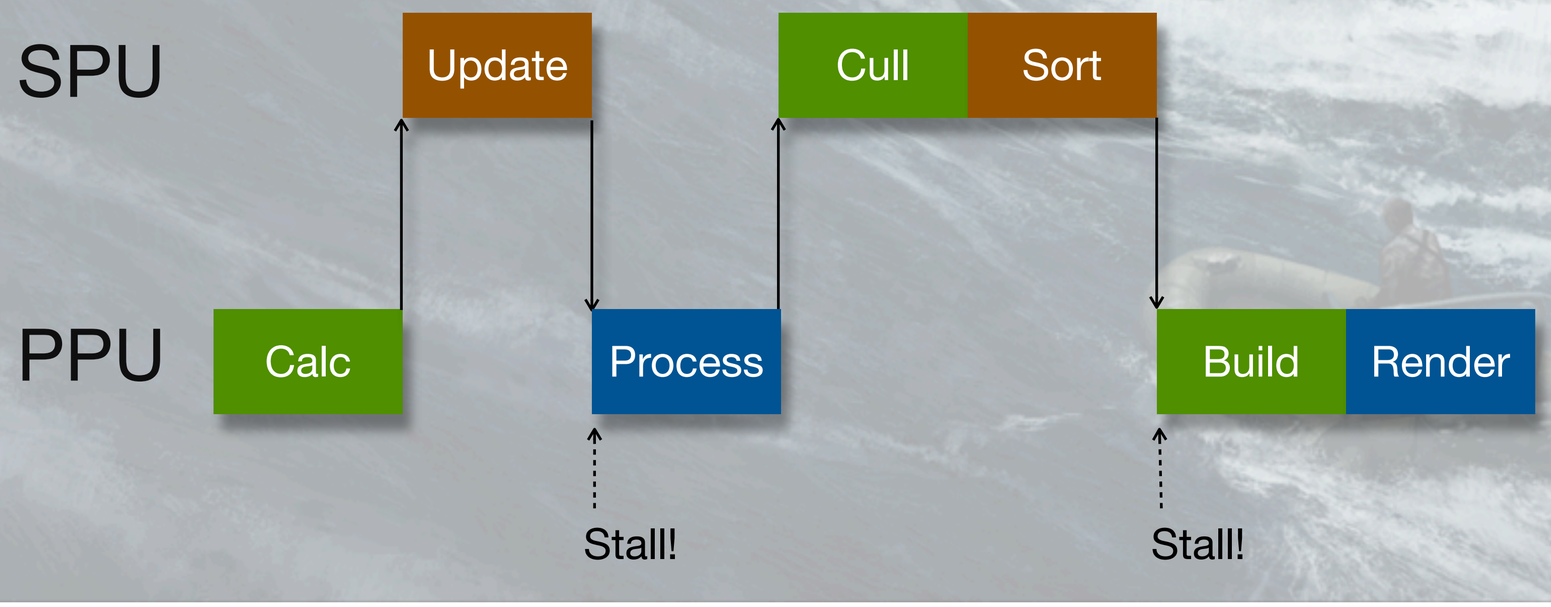
Design goals
Description and demonstration of tools used by VFX artists
Get into runtime architecture – data structures and spu job chain
Usage example – sand prints. Surface projection shader.

UNCHARTED DRAKE'S FORTUNE Particles

- Scheme based macro language
- Ubershader
- Processing split between PPU and SPU



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Effects system used in Uncharted 3 began development after UDF
UDF system was difficult to use, felt that to produce quality & quantity of fx, we needed to rework.
FX artists write FX in scheme based macro language, rebuild, upload. Hard to visualise.
Shader was 6000+ line ubershader, brittle and difficult to use, so most effect shaders were very simple.
On runtime side, processing was split between PPU and SPU, stalling on the PPU for jobs to finish.
OK for initial PS3 title, but we needed to be more efficient for sequel!

New System

- Drastically improve iteration time
  - Faster iteration == more effects & polish
- More data driven
- Better dynamics
- More flexible shaders with modern features
- 100% asynchronous SPU code

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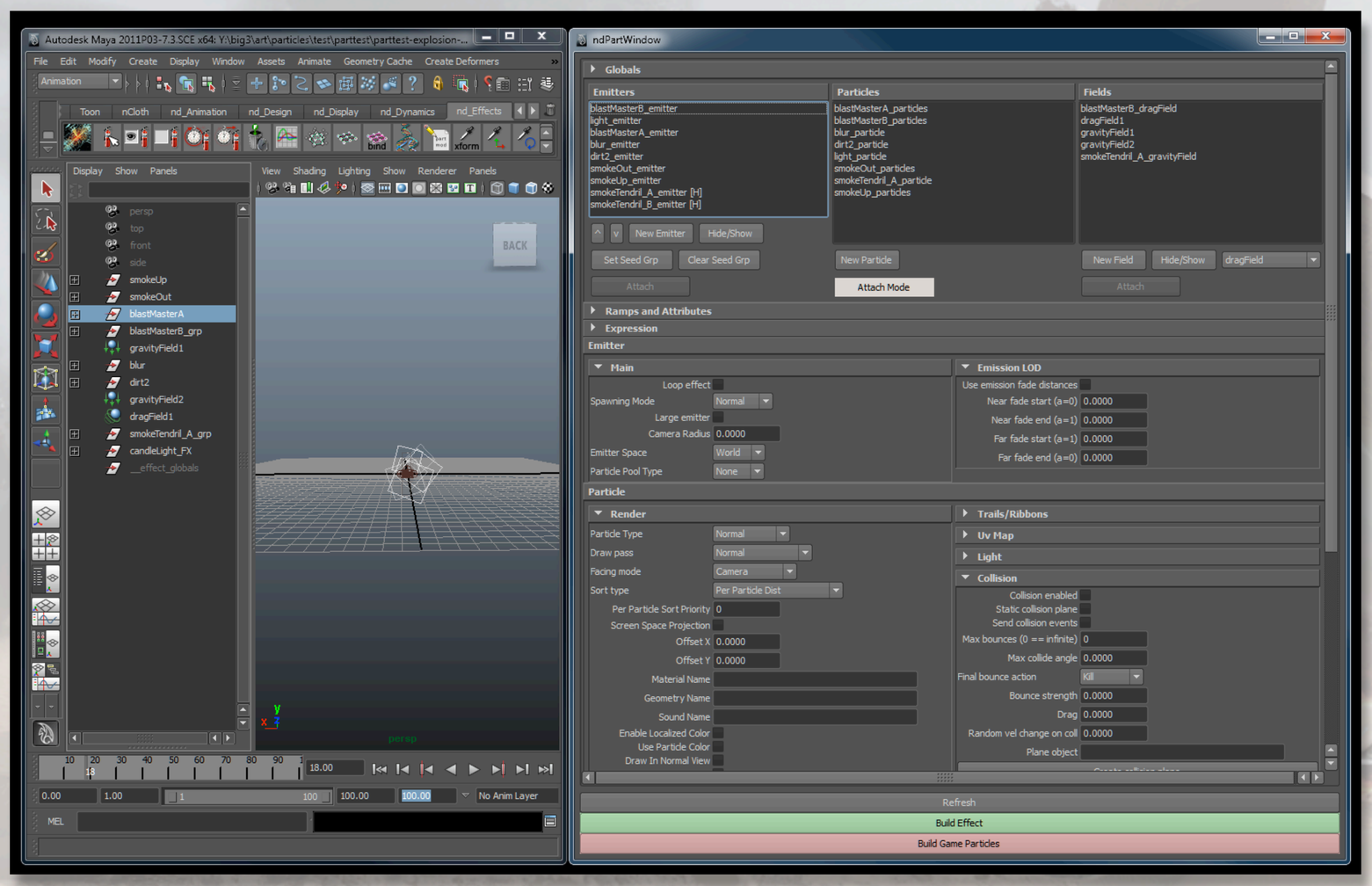
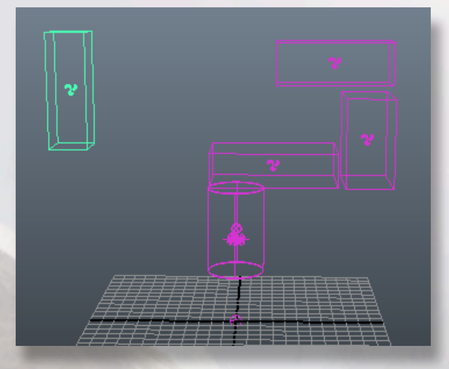
These issues informed design for new system
Iteration - artists should see changes when they build
Data - more artist control. Curves, ramps, custom data
Dynamics - add fields to change velocity
Shaders - more modular, easier to use & modify, new features - distortion, soft particles
Move rest of code to SPUs, remove sync points. 2.5 to 4x bonus from naive port.

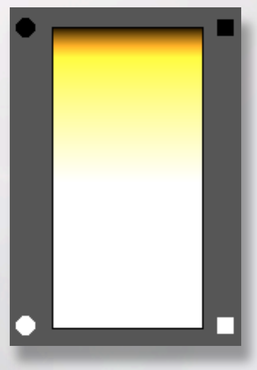
Tools

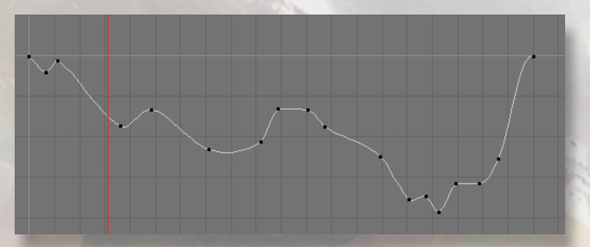
- Particler (Particle authoring)
- Noodler (Shader creation)

Particler









```
float $colorOffset = rand(.4,1);              float $color
vector $intlColor = <<$colorOffset,$colorOff vector $intl

rgbPP = $intlColor * ndi_colorRamp;           rgbPP = $int
opacityPP = 1;                                opacityPP =
frameNum = (age * 30) + ndi_opacityRamp;      frameNum = (

float $colorOffset = rand(.4,1);              float $color
vector $intlColor = <<$colorOffset,$colorOff vector $intl
```

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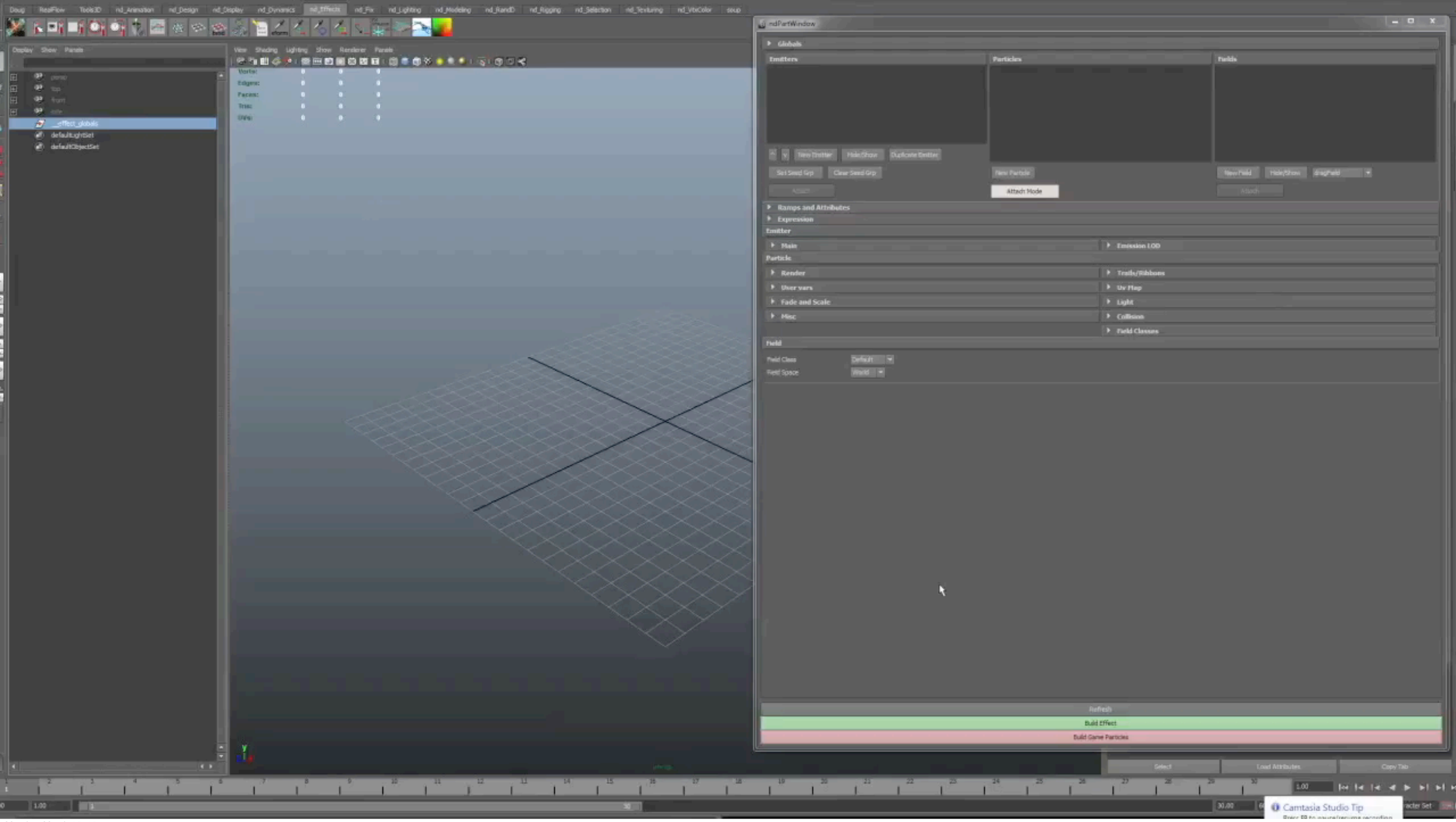
Particle authoring tool
Runs on maya, written in Python using Maya UI commands
U1 was difficult to get a new FX artist up to speed, we wanted tool artists could use right away
Basing on maya was obvious choice

Particles created using Maya's particle nodes (emitters, shapes, fields). Ramps and curves attached to most parameters. Particle expressions.
Show demo. Doug creates a single emitter smoke effect with an animated turbulence field.



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Create effect by placing a set of emitters
Each emitter independently configured
Emitter, particle shape, field windows

(Describe workflow?)
A particle artist creates an effect by compositing multiple simple particle elements in Maya. Each element has its own configuration, the shaders, fields, and emitters can all be separate. The final effect is placed and spawned as a single unit known as a particle group.

(other stuff to talk about)
The artist can attach fields to the emitters. Fields are similar to the fields found in Maya particles - they modify the current velocity of the particle in some way. For example, a drag field will decelerate the particle in proportion to it's current velocity. A gravity field will accelerate the particle in a specified direction by a fixed acceleration.

2 minute demo video here with basic operation of Particler?

Items to include in the demo:
Create emitters and shapes, and attach them
Create fields and attach to emitters
Edit animation of emitter
Edit a color ramp
Edit script
Show and hide different elements
Build and show each part in game

Info from particler slides to work into the narration. Discuss some but not all!

Emitters: Point, Volume; Continuous, burst, and distance emission; Speed & Lifespan w/random variance; Inherit velocity from parent
Fields: Types: Gravity, Drag, Air, Radial, Vortex, VolumeAxis, Turbulence, Kill; Volumes for attenuation; Most parameters can be animated
Curves & Ramps: Curves stored as cubic splines; Curves are used with emitters and fields; Ramps can be used with particle expressions
Expressions: Applied to particle state; Artist can define extra state vars; Expressions compiled to byte code (more on this later)

Building the Effect

- Information extracted from nodes for export
  - Particle definitions
  - Fields
  - Curve & Ramp Tables
  - Expressions
- Compile expressions into VM byte code
- Write all data out as DC format

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When effect built, Maya scene is traversed and game data is gathered from emitters and all attached shape and field nodes.
Curves and ramps attached to attributes are collected in tables.
Expressions are parsed and compiled to VM byte code
Data written in DC file

DC

- Data Compiler
- Used for most runtime data
- Scheme based

(For more info, check out Dan Liebgold's GDC 2008 presentation)

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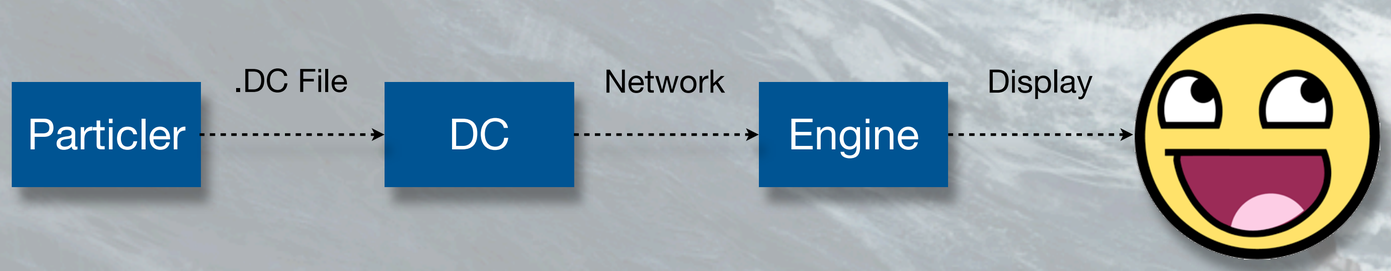
DC - human readable format used for gameplay data.
File gets converted into binary by the Data Compiler tool, hence DC. Built on top of Scheme.
Dan Liebgold gave a presentation at GDC in 2008 talking all about it.Available in slide and audio in the GDC Vault.

Particler to Game

- Particler spawns interactive DC session with plugin
- DC persists to speed up future builds for quick iteration



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Once the DC file is created, Particler then calls a custom Maya plugin that launches an interactive DC session and connects to it via a pipe. Particler then sends the DC session commands to compile and upload the file to the game. DC has a network connection directly to the runtime, and can send it commands to reload binary data files, replacing the copy that it already has. The runtime then resets the spawned particles and uses this new copy of the file to respawn the edited effect. The new effect is then displayed for the artist, who can quickly review his changes. The DC session is kept alive to process further commands from Particler, so iteration time is very quick and requires no more from the artist than tweaking whatever items they want to change and hitting the build button. So that's Particler.

Noodler

- Rewritten shaders still not flexible enough
- Sony ATG demos editor for us - let's try it

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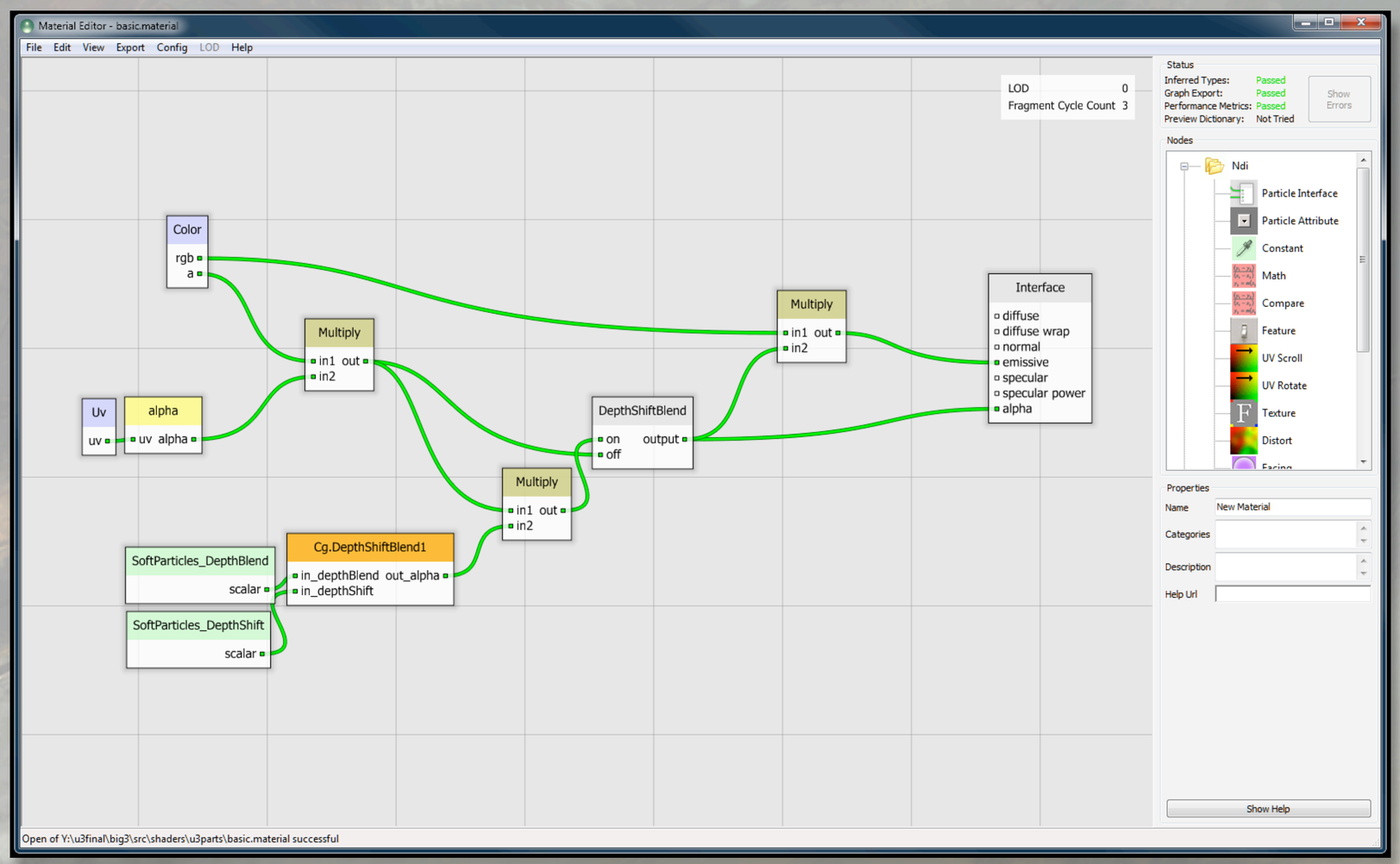
Artists could not experiment
Node based shaders = slow and hard to debug?

Write shaders for U2 but overwhelmed with artist requests
Mike D asks for node based editor so he can write his own shaders
No, shaders too slow and hard to maintain.
Right before U3, Sony ATG shows material system with NBE
Decide to give it a shot since it was ez to integrate

Noodler



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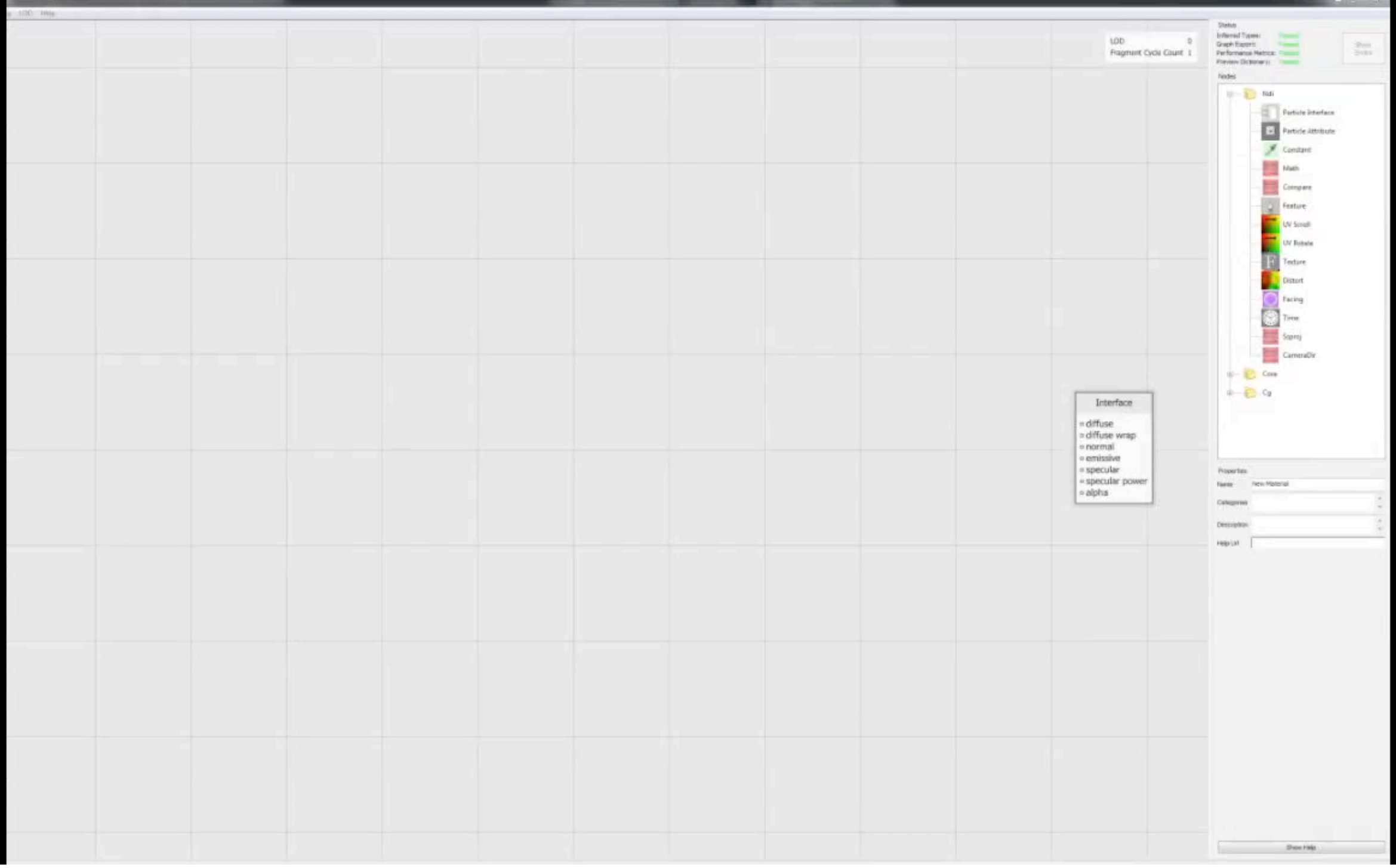
Noodler - node based editor. It's written in C++.
All vertex inputs set up
Color and alpha outputs to interface node
Can use external lighting as defined by game
Provided nodes: math, texture, attribute, ???
Can define nodes by writing cg functions (cool!)
Short demo putting together a shader and bringing it in game



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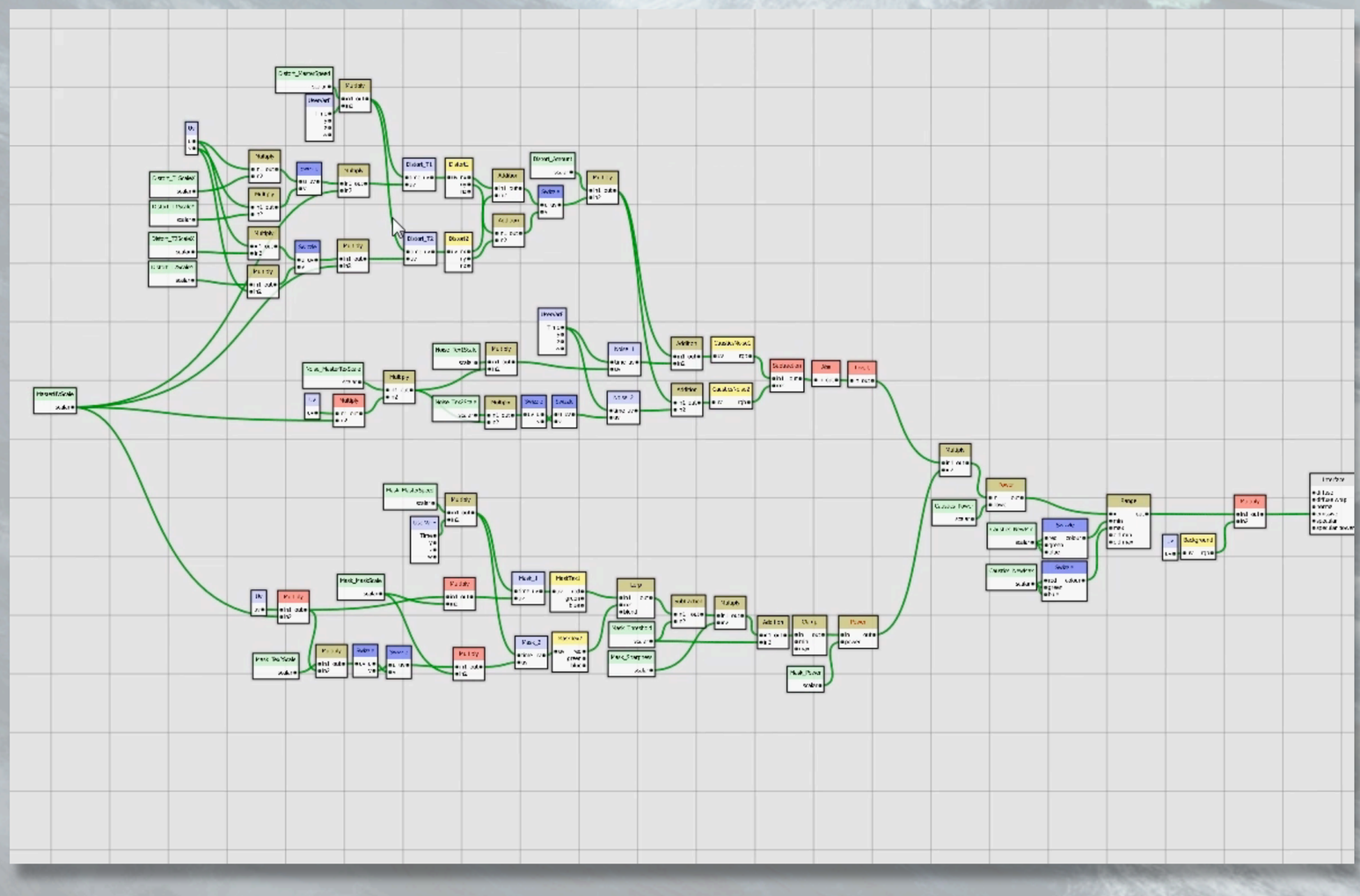
Demo video here for noodler!

Ideas:
Build a simple blend shader
Drop into surfer, connect up textures
Preview

Caustic Shader



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After editor integrated into tool pipeling, gave to Eben Cook to try and get feedback
Within a day, he had written this shader
<show noodler graph of caustic>
Shader fakes water caustics reflected onto a surface
Previously used flipbook, required a lot of texture memory
This shader uses no textures for caustics, and only requires 19 cycles
Here's the final result:
<show video of caustic shader, compared with the flipbook>

Noodler Internals

- Vertex frontend - define input attributes
- Interface node - outputs fed into lighting code
- Each node is a Cg function
- Automatically split into VS & FS
- Automatic space conversion

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Vertex frontend – defines functions that convert vertex registers to attributes used inside the tool
Interface node – output sink for the graph, used by lighting backend to render final color
Each node is turned into a Cg function
Automatically checks type agreement
Automatically splits VS & FS, but you can override
Handles attribute passing between VS and FS by swizzling VS outputs automatically
Handles converting space changes for vectors and points

How did it go?

- Noodler used for all FX shaders in U3!
- Programmer help needed for some debugging
  - Decreased over time as artists learned more
- Made artists manage their cycle budgets

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Super fast iteration
Artists could create unique shaders that improved the dynamic look of their effects
Programmer help with numerical issues, render state, some debugging
Cycle counts were fairly reasonable

Spawning Effects

- Spawners in Charter (Level Editor)
- Script
- Animation effect files (EFF)
- Water Spawners
- (directly in code too)

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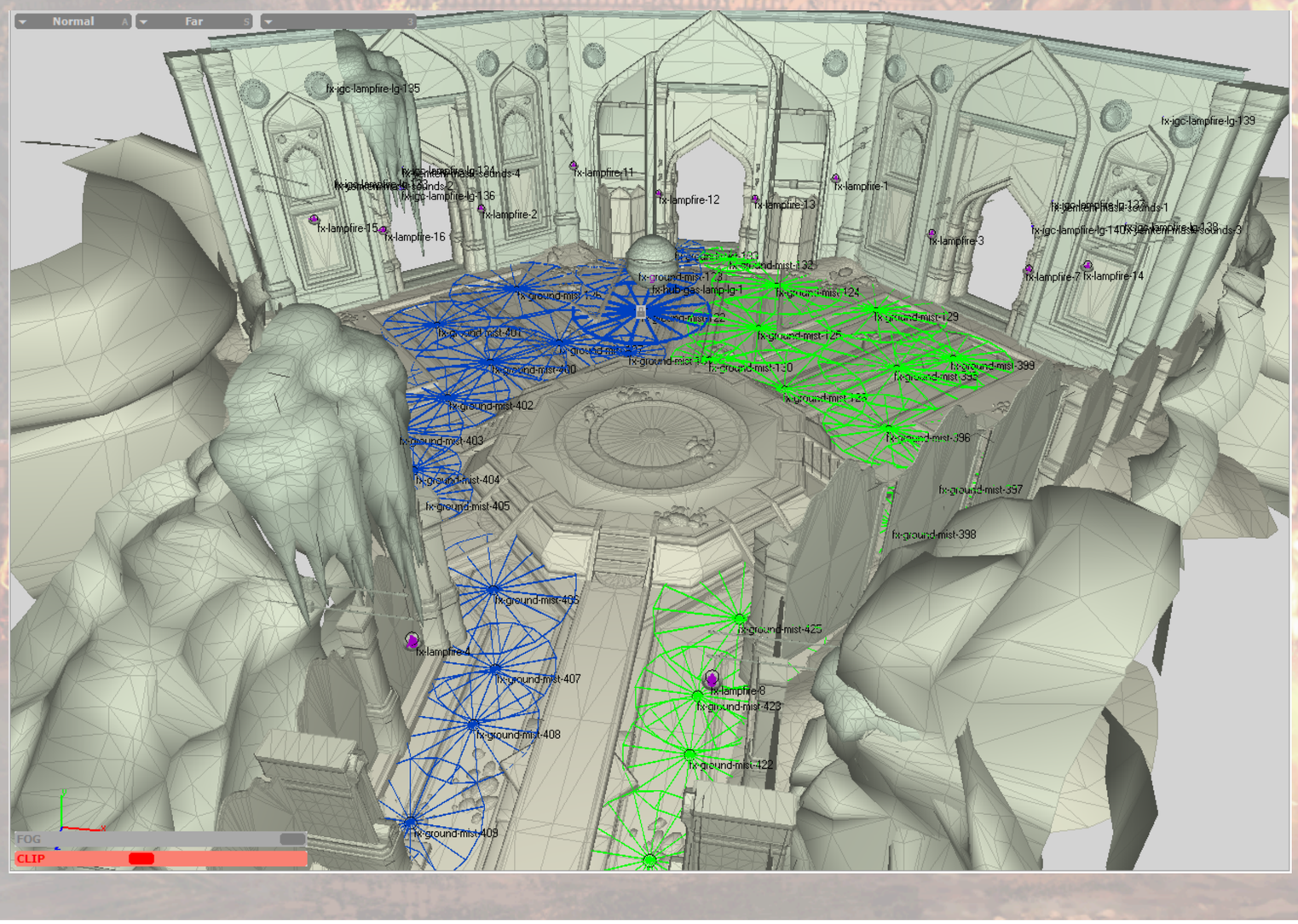
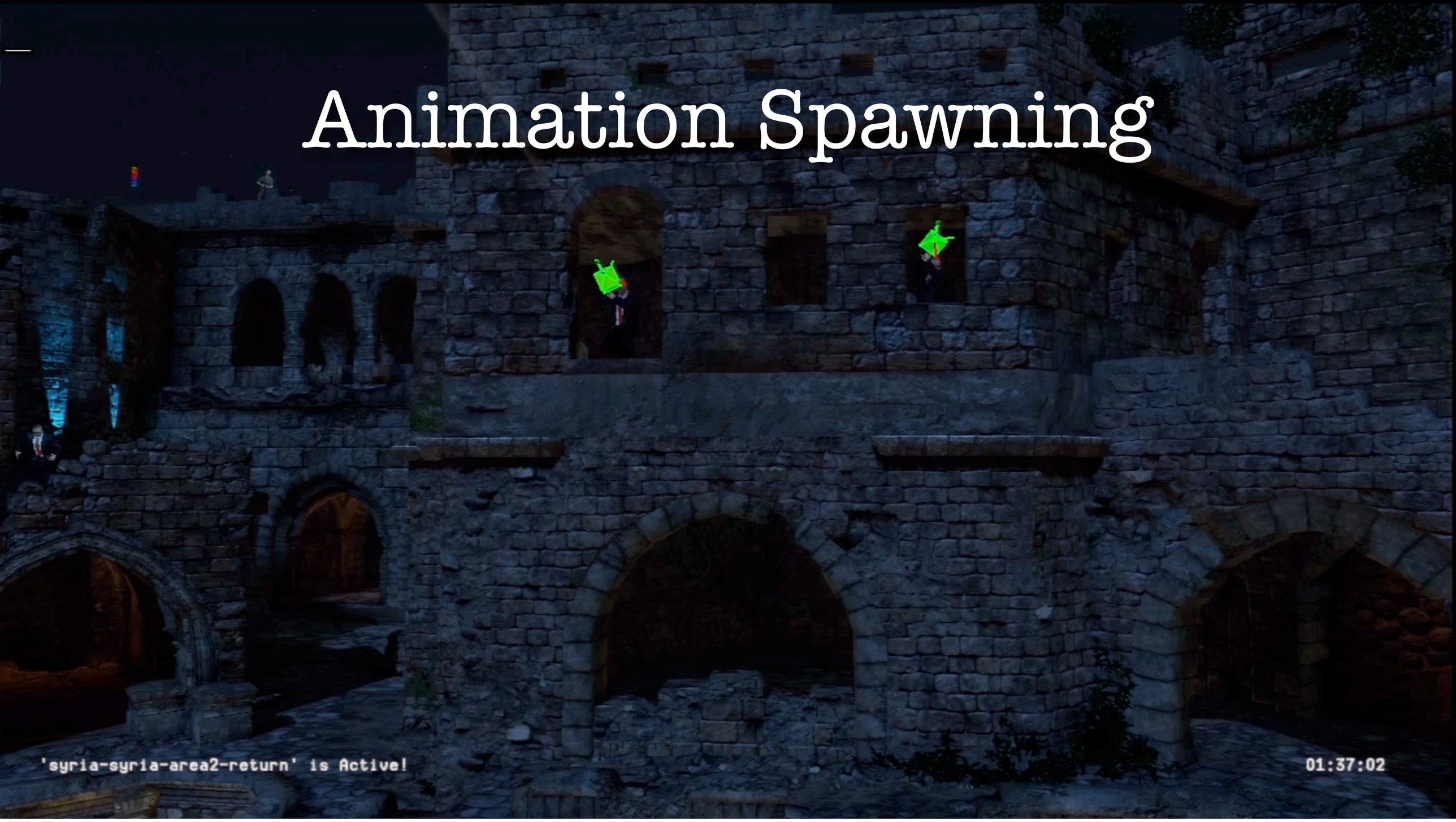
Once loaded, how do you create?
Environmental effects - spawned when camera enters an associated region
Animations - Specify keyframe and joint
Script - using spawner location
Code - not used much but available (projectiles)

Charter Spawning




Script Spawning
'chateau-cha-manor-south-roof' is Active!
00:07:11

Animation Spawning



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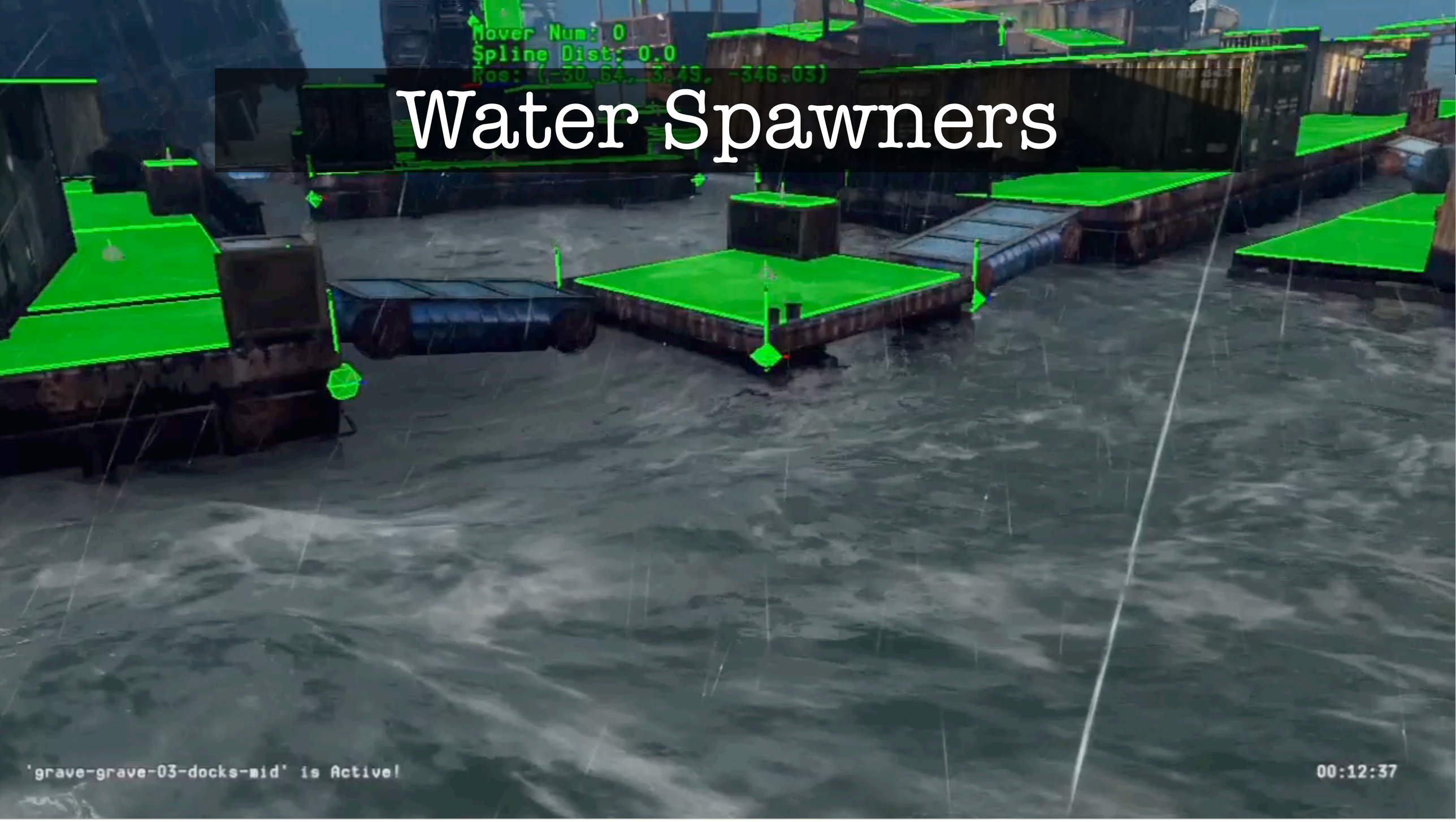
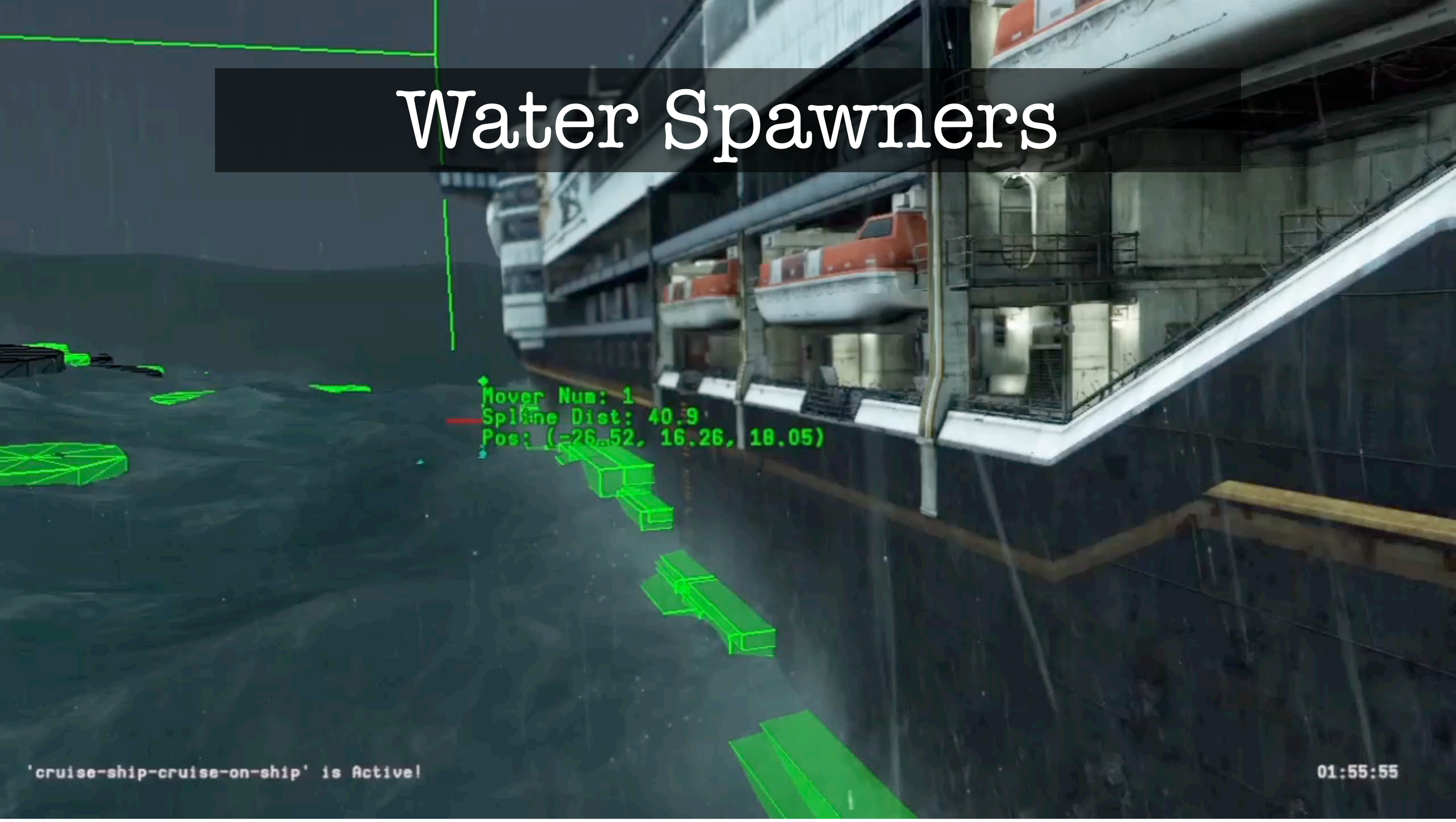
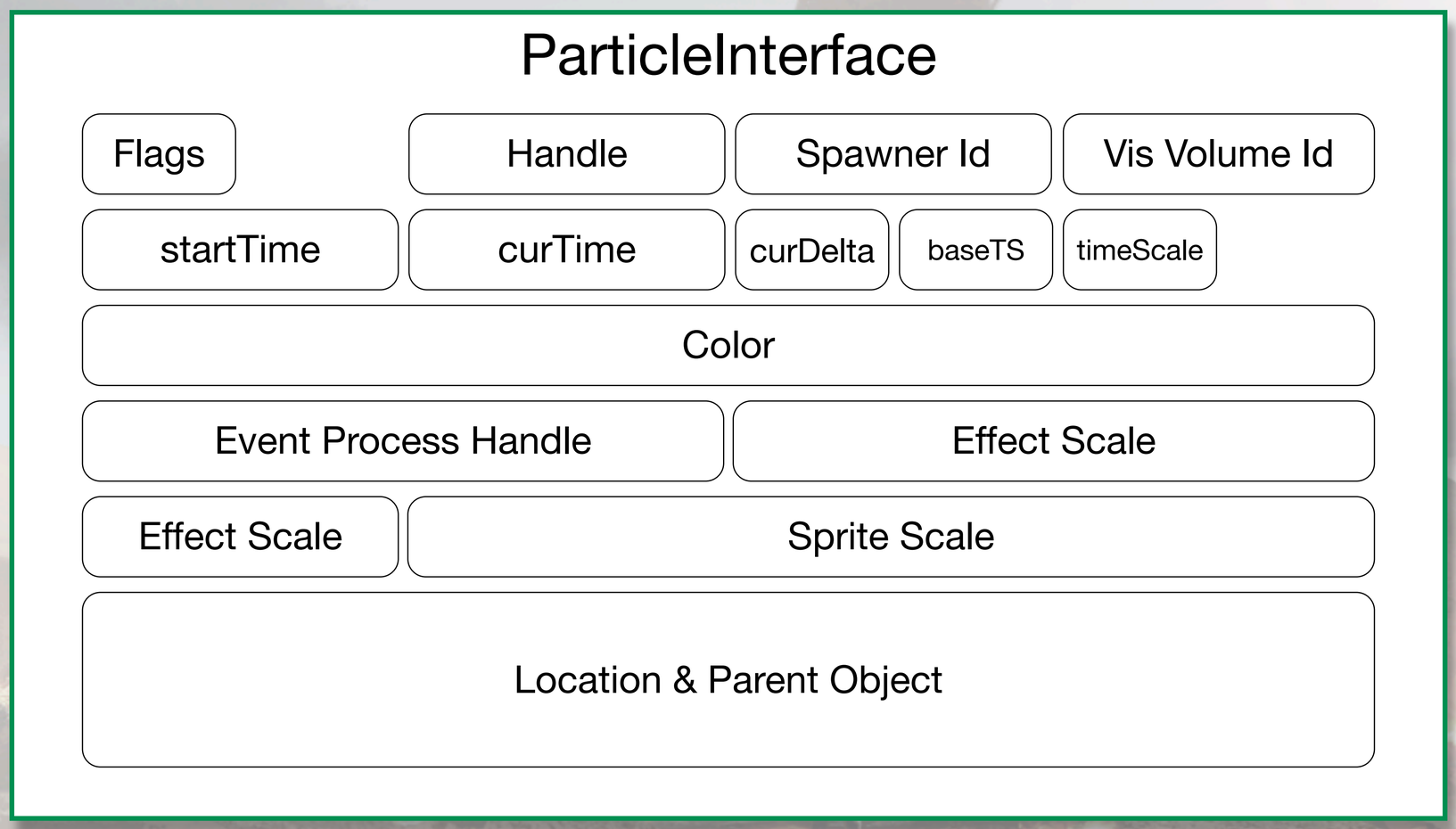
Water Spawners



Water Spawners



Particle Interface



Can also control some properties while running effect, using root data
RootData contains information used by an entire effect
Bound frame most important, controls position and orientation of effect, good for fx attached to objects (platforms, weapons)
Color, scale, alpha – modulate effect properties
Time variables – we can control playback speed or pause
Good for playback variety, preroll – smoke column
Vars can be changed using script functions, or by values set on spawners

Runtime Design

- System designed with hardware and engine in mind
  - GPU cycle budget for particles very limited
  - SPUs provide ability for complex computation
  - Less particles, but more processing for each one

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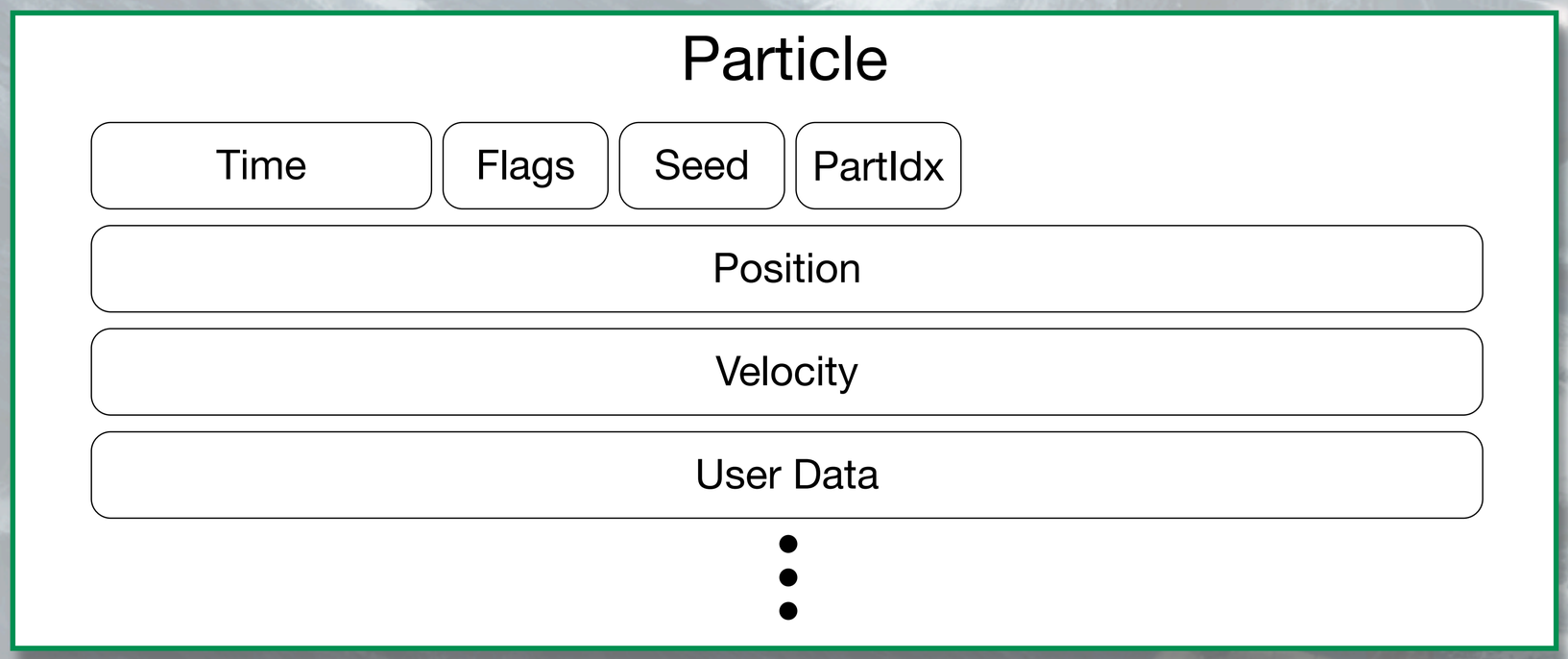
GPU has a much higher load: fp16, deferred lighting, and full screen post
Wanted to take advantage of the SPU horsepower of the PS3.
We can get complex motion from each particle through shaders and expressions

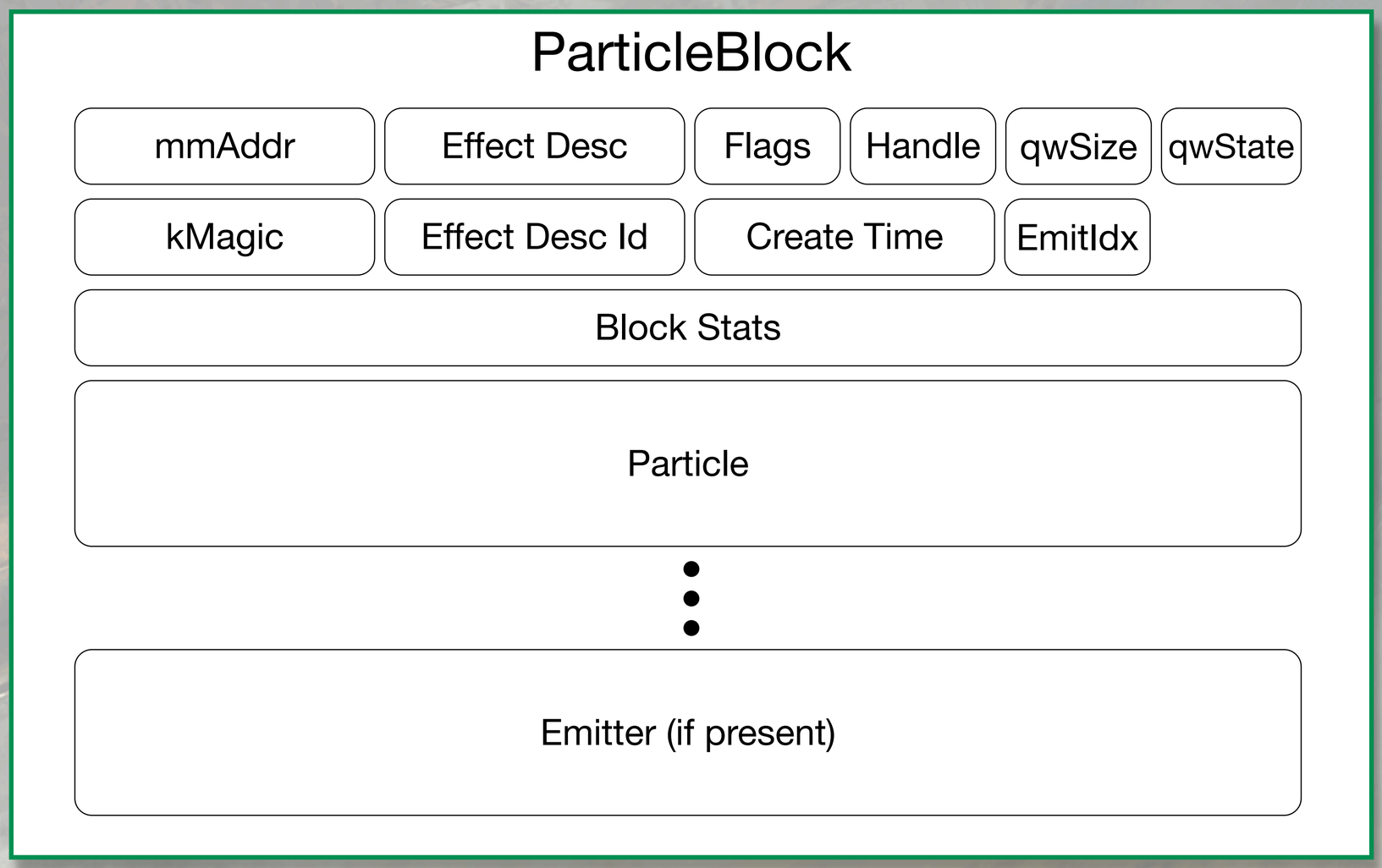
Particle Structure



All data for single particle
Spawn time, status flags, random seed, pos, vel, state data
Variable size user data based on type
All particles of a given type have the same size

Structure is a multiple of 16 bytes, aligned.
Minimum size of a particle is 48 bytes, typical size 80 bytes

ParticleBlock Structure



Particles from a given emitter are stored together in a particle block.
Max size 16 kb, so emitter can have multiple blocks.
Pointer to effect desc which contains the info how to update and draw particles
Can contain an emitter as well. Emitter = particle structure with a couple of extra vars for lifespan and next spawn time

Particle Frame

- Preupdate
- Update
- Cull
- Build Geometry
- Sort
- Build Render List

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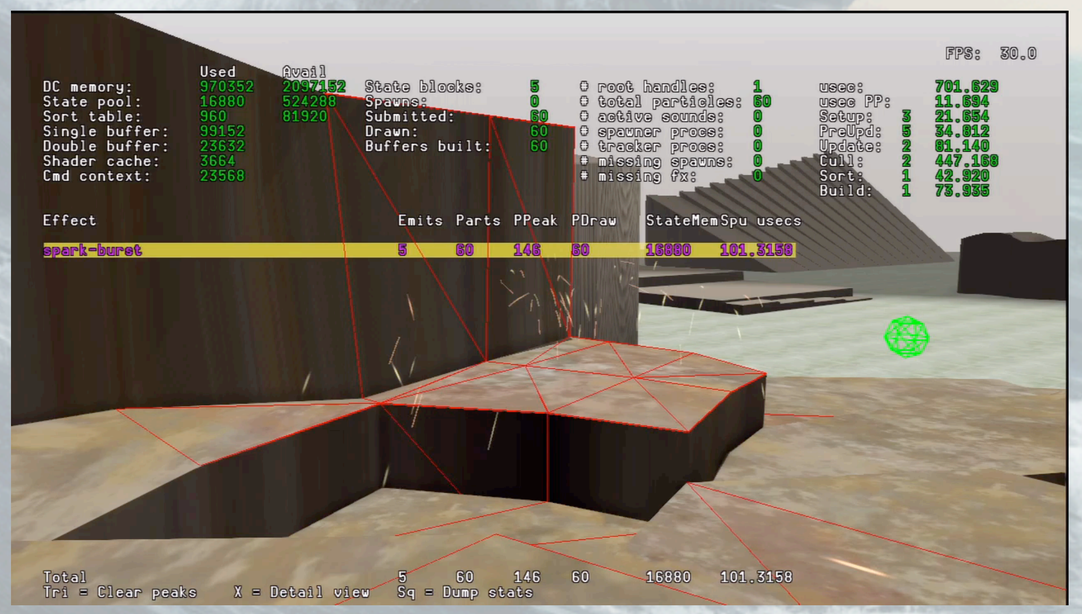
Preupdate - Spawn, kill, movement and collision
Update - Apply field forces, run bytecode
Cull - Frustum cull particles for drawing
Build Geometry - create vertex & index buffers, attach to items for rendering
Sort - sort particles by distance and spawn time
Build Render List - create command buffer for GPU. Shader and state setup.

Preupdate - Collision

- Per particle collision vs. environment
- This is too expensive!
- What can we do?
- Approximate!



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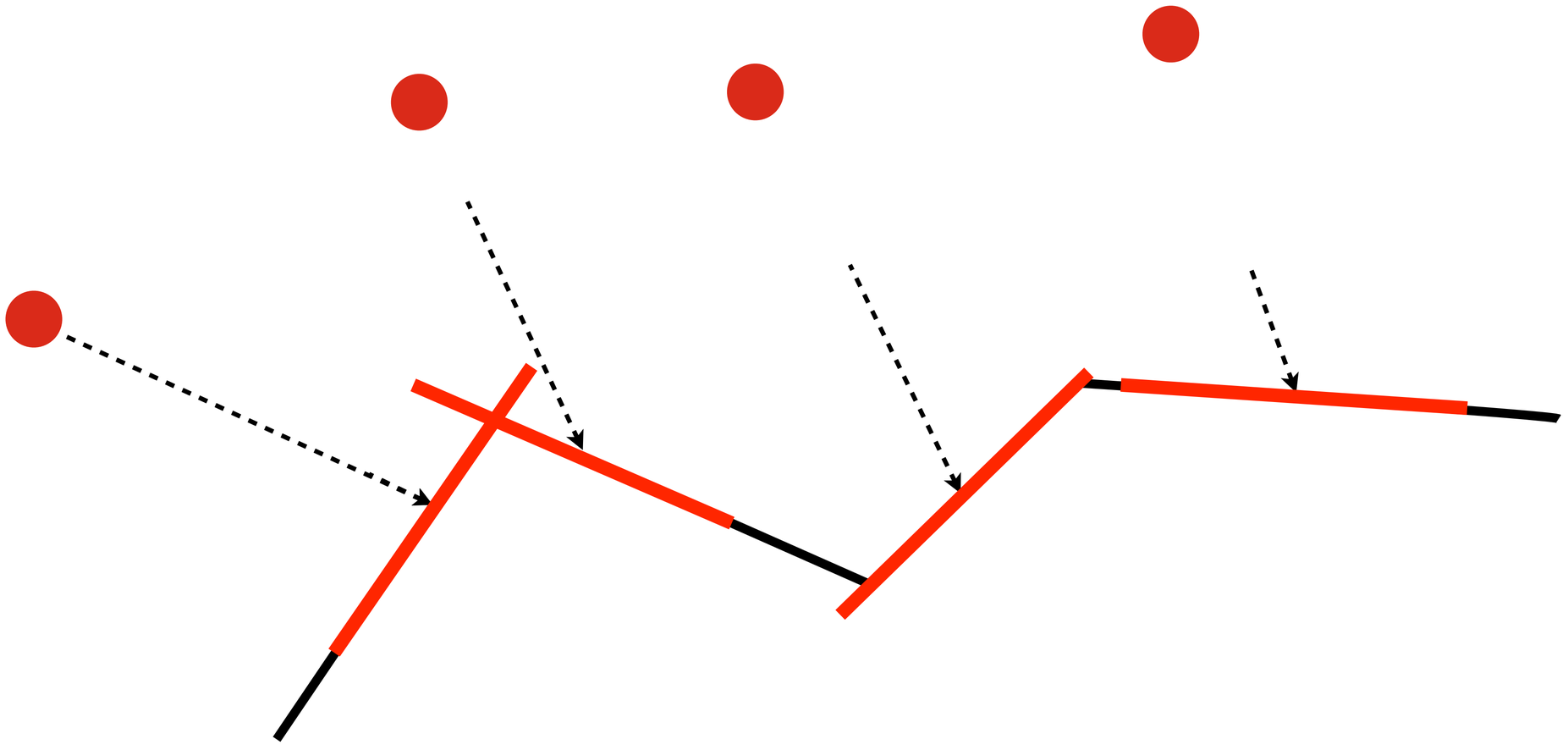
After particle moves, we do collision check to see if it collides with environment, and resolve the collision here
Doing per particle check vs. environment every frame too expensive
Solution - approximate with cached collision planes

Preupdate - Collision



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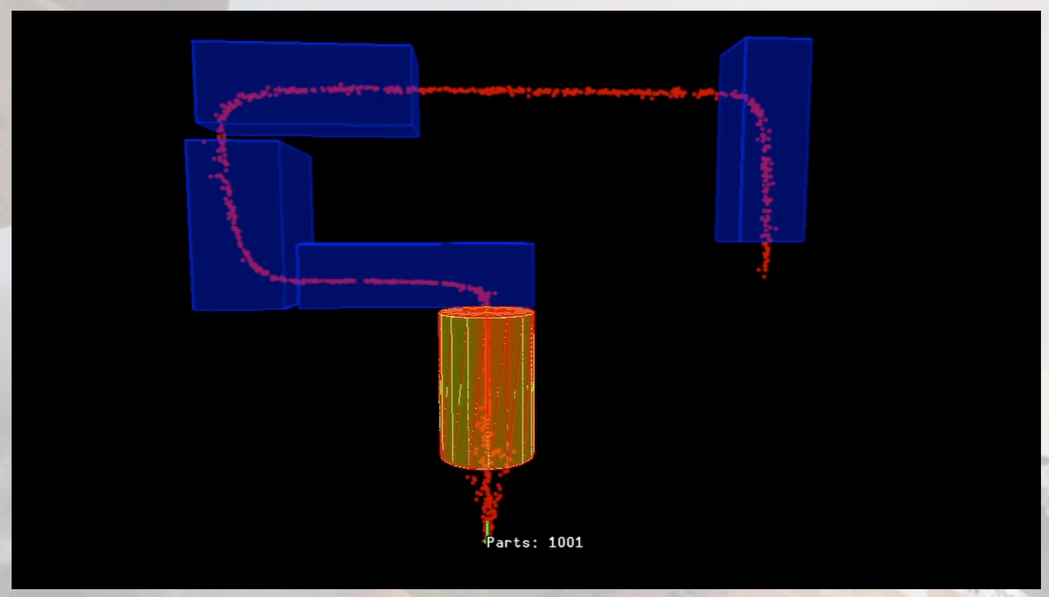
Each particle stores a collision plane, we collide against that
Every frame, we select a subset of colliding particles (10) and kick off ray cast vs environment for them
Result is returned next frame, and stored in the particle data
Particle planes update in round robin fashion
Per frame cost is low, results are acceptable
Some particles will fall through geometry, in practice this isn't noticeable

Update - Apply Fields

- Gravity, Turbulence, Drag, Volume Axis, Radial, Vortex
- Bake animated parameters
- Test vs. volume
- Apply forces to velocity



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Update first applies fields to each particle
All parameters animated, bake using curve data and time
Particles processed in vectorized SOA format, 4 at a time
Test all particles against each field volume, to determine how much if any force to apply
Calculate change in velocity, scaled by attenuation, add to particle velocity
Velocity applied on next frame

Update - Byte Code Exec

- VM with 16 vector registers
- Non branching
- Creation and update expressions

```
(particle-expr runtime
  (lconst 0 2)
  (lconst 1 2)
  (lconst 2 2)
  (store 10 0)
  (store 11 1)
  (store 12 2)
  (ramp 0 1 0)
  (store 9 0)
  (ramp 0 0 0)
  (store 13 0)
  (load 0 13)
  (store 14 0)
  )
```

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Execute particle expression byte code
SPU job implements VM with 16 vector registers, non branching opcodes
Particles processed here in SOA format as well
Expressions mostly used to update color, alpha, scale, and user params (check this)
Seperate creation and update expressions

Cull & Build Geom

- Cull vs. View Frustum
- Build Verts
- Create Indices & Render Data Structure
- Write to Memory

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Cull - one block at a time. flags particles to draw, reserves space for vert and idx data
Build - extract particle state into a ParticleState structure, which bakes out ramps and copies state data to fixed structure.
Build vert buffers
Some sorting is done here, more detail later
Generate indices, and attach all data to render data structure used by build. Generally all particles in block will be written as a single batch.

The cull job processes one ParticleBlock of particles at a time. First, it culls all particles in the block against the view frustum and sets a flag on the particle. After this, it reserves space for all the visible particles and creates vertex and index data for each particle.

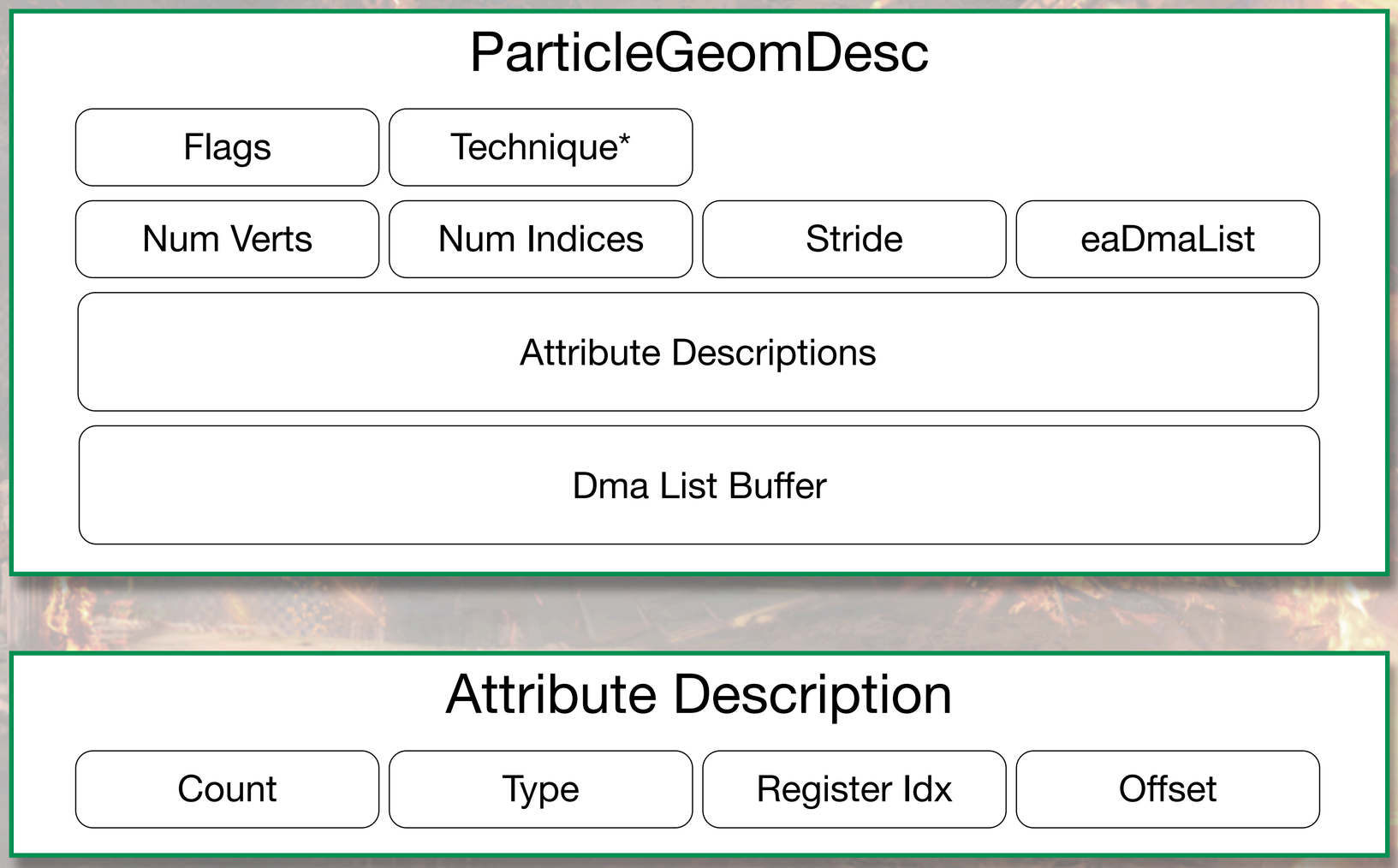
Particles are tested to see if they are within the view frustum. If the particle passes, we construct vertex data for it and adds a render data structure to the list of particles to be sorted and rendered. The particle state is extracted into a ParticleState structure which contains all the possible attributes that can be used by a shader. These attribute values can come from constants, state data, or ramps driven by the particle state. These values are used to set up the vertex data according to the Attribute Descriptions in the geometry description. The particle vertex data is then added to an output list that is sorted after the block is completely processed.

After all particles in the block have vertex data generated for them, the output list is sorted if required by to the sort type selected for the effect in the particler tool. Sorting is somewhat complicated so I will explain the particulars when we get to the sorting job later, but for now it will suffice to say that the sorting is split between the cull job and the sort job, in order to reduce main memory usage and sort job processing load.

After the sort is done, we generate indices for the particle geometry, and create a Sprite Render Data structure that has pointers to the vertices, indices, and the geometry description DMA list. Generally all particles in a block will be written as a single batch with one render data structure.

Finally, we reserve some space in main memory, and write all the generated render data.

Geometry Description



Data used to describe how to set up vertex buffers and render the particle
Attribute descriptions tell cull and build job how to layout the vertex buffers
The dma list is used to transfer the shader for the build command list job

Sorting

Spawn Order

Distance

Sorting back to front by distance not necessarily good
Sometimes spawn order is better, artists have better control when authoring the effect
Can also control order of emitters within an effect to have a well-defined layering
Radix sort of all render batches.
Do some of the work in cull to allow for more particles and reduce the load here and avoid a merge sort

Sorting

- Sorting for each emitter set in particler
- Distance, Spawn order, Reverse spawn order
- Artist can set emitter draw order in particler

Sort methods
Per emitter or per particle
Dist, Spawn order, Reverse spawn order

Build Command List

- Outputs command list for RSX
- Set up viewport, shader, render state, vertex format
- Cache shaders and settings

Groups particle batches by draw pass and render data to minimize state and shader changes
Set up viewport, shader params, render state, and vertex format
Draw batch
Caches settings between batches for reuse

Setting up the Job Chain

- Want to run on all SPUs
- Don’t want to have the PPU involved after kick
- Each phase must finish before next phase runs
- Can’t tell how many jobs we need for each phase

We have jobs to update and render particles
Each job depends on data from previous
We don’t know how many jobs we need in each step until previous is done

Setting up the Job Chain

- Use setup jobs to gather results, and set up new jobs

Job Chain

Execute SetupStart Job

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We use setup jobs to schedule other jobs
Heres how we build job chain
PPU adds SetupStart and kicks it, for the most part PPU done here
SetupStart adds preupdate jobs. Blocks batched by emitter type in 16k buffers, 1 job added per
Barrier and SetupUpdateCull added. Barrier prevents job mgr from taking more jobs until all preupdate are done.
Run preupdates. Reads old state data and writes out new state data. Allocations and size can change
SetupUpdateCull adds update and cull jobs, with barriers between and after. Same logic as preupdate for # of jobs. Add SetupSort and render data barrier.
Updates run and output in place. Culls run.
SetupSort runs and sets up the sort job with cull data.
Sort job runs, adds build jobs to build each pass necessary.
Builds run. That’s it!

Job Chain

Execute Preupdate Jobs

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We use setup jobs to schedule other jobs
Heres how we build job chain
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Job Chain

Execute SetupUpdateCullJob

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We use setup jobs to schedule other jobs
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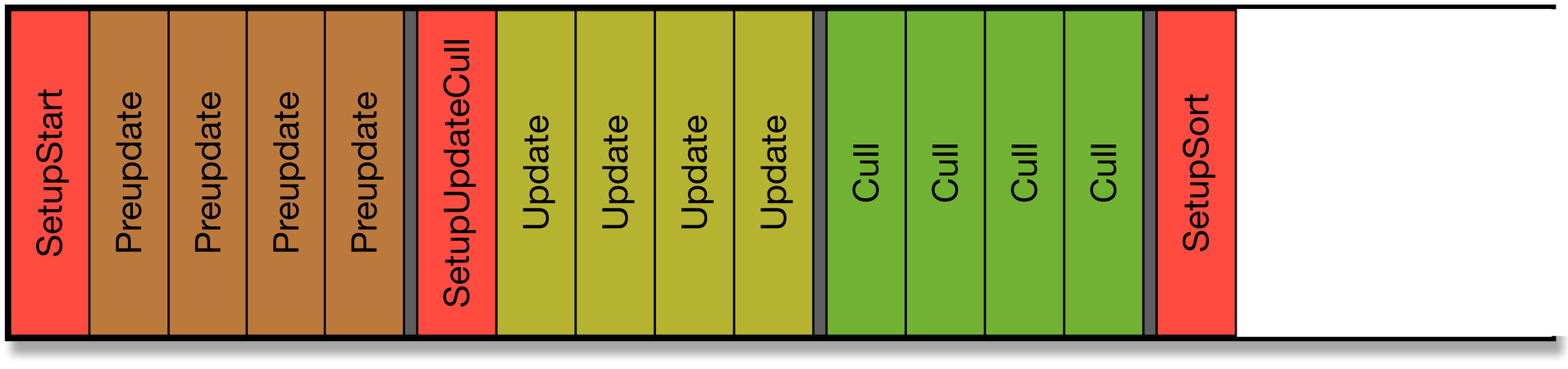
Job Chain



Execute Update and Cull Jobs

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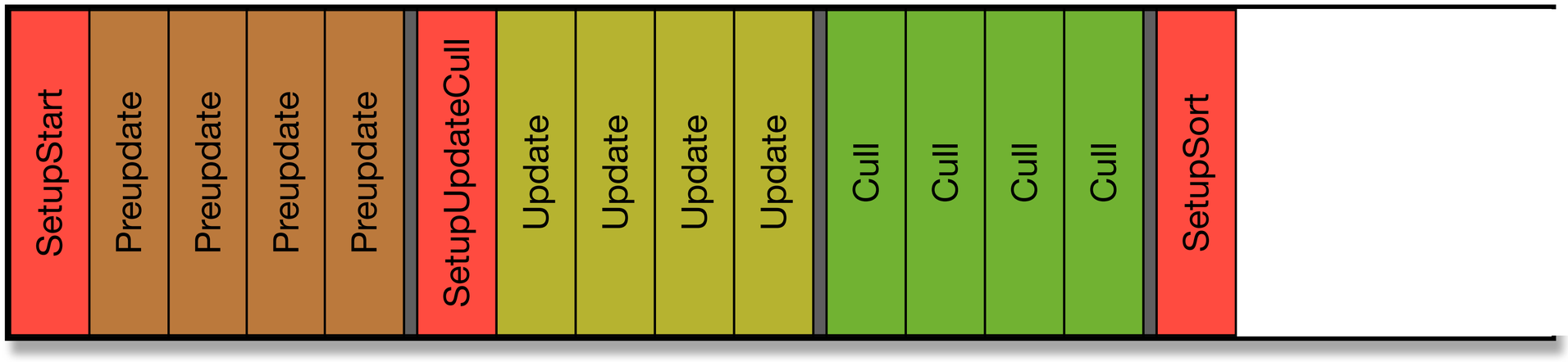
We use setup jobs to schedule other jobs
Heres how we build job chain
PPU adds SetupStart and kicks it, for the most part PPU done here
SetupStart adds preupdate jobs. Blocks batched by emitter type in 16k buffers, 1 job added per
Barrier and SetupUpdateCull added. Barrier prevents job mgr from taking more jobs until all preupdate are done.
Run preupdates. Reads old state data and writes out new state data. Allocations and size can change
SetupUpdateCull adds update and cull jobs, with barriers between and after. Same logic as preupdate for # of jobs. Add SetupSort and render data barrier.
Updates run and output in place. Culls run.
SetupSort runs and sets up the sort job with cull data.
Sort job runs, adds build jobs to build each pass necessary.
Builds run. That’s it!

Job Chain



Execute SetupSort Job

Monday, March 12, 12

We use setup jobs to schedule other jobs
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PPU adds SetupStart and kicks it, for the most part PPU done here
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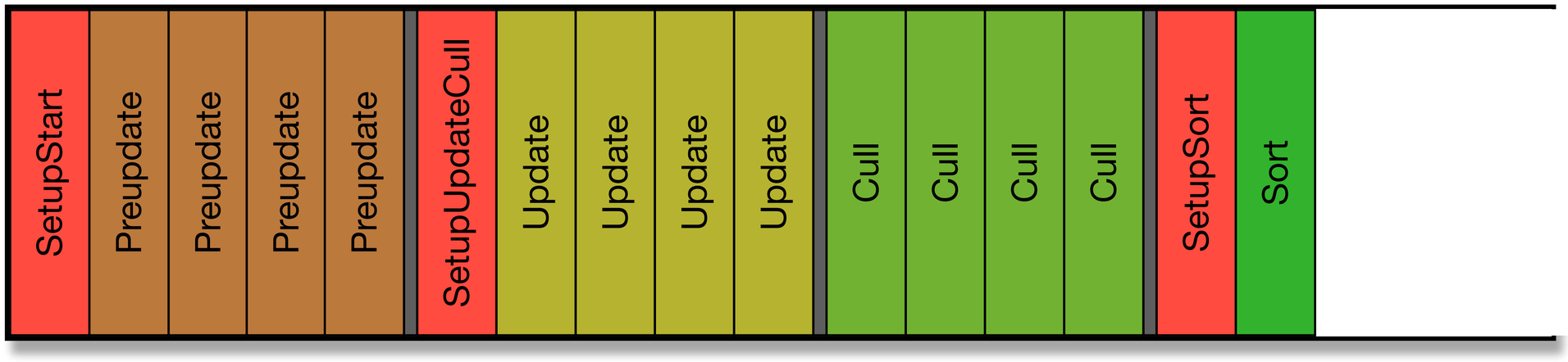

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Monday, March 12, 12

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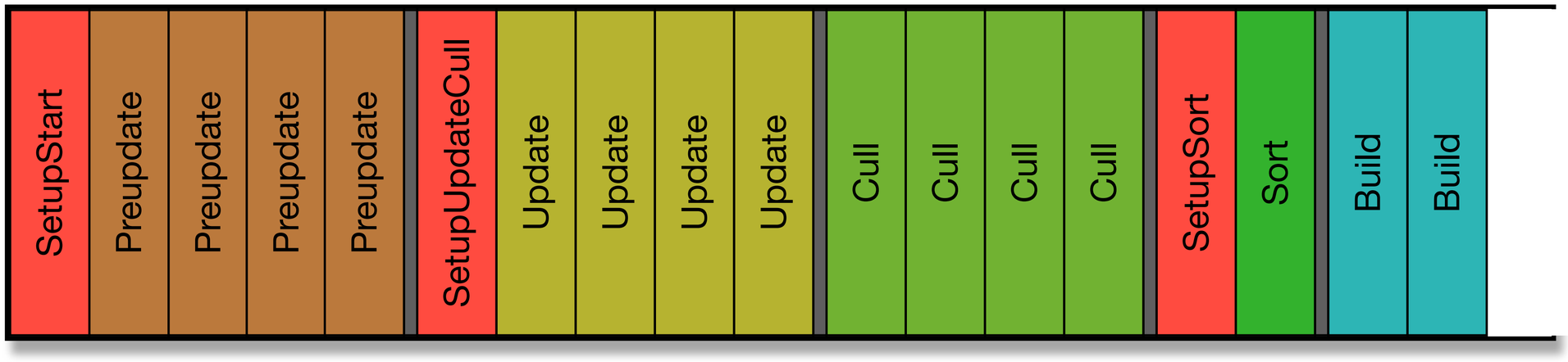
Job Chain



Execute Build Jobs

Monday, March 12, 12

We use setup jobs to schedule other jobs
Heres how we build job chain
PPU adds SetupStart and kicks it, for the most part PPU done here
SetupStart adds preupdate jobs. Blocks batched by emitter type in 16k buffers, 1 job added per
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Sand Footprints

Drake spends a lot of time walking in desert
Early on, we discussed ways to make realistic dunes
Dust blowing and nice sand shader, we wanted to deform sand as Drake struggles up and falls down the dunes
Ref video shot at Imperial Sand Dunes, in socal. Keith G standing in for Drake

Example - Sand Footprints

- Deform the surface
- Animate the deformations
- Match lighting model of BG
- What to do?

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Clearly a lot of deformation and movement when Drake moves over sand

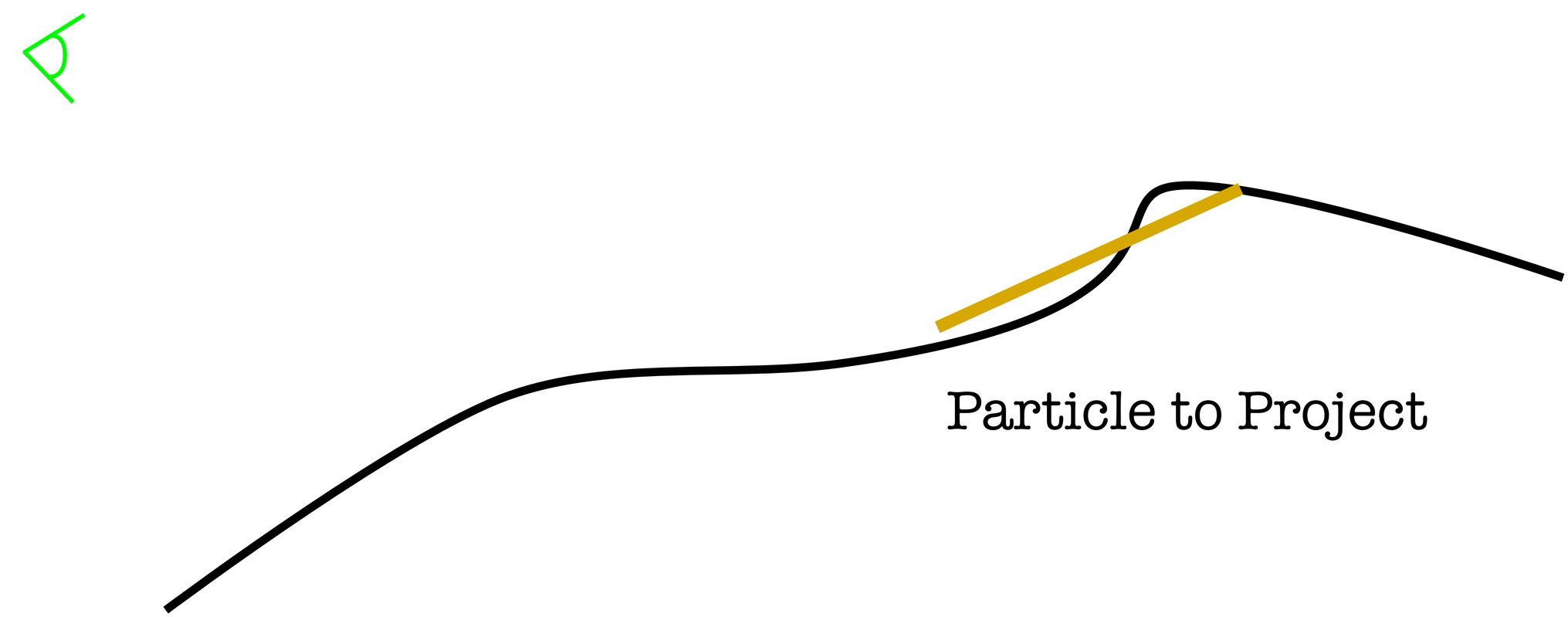
How can we replicate? Deforming prohibitive
Fortunately, we've done something like this before...

U2 - Snow Prints

- Screen space projection for foot decals
- Static
- Specifically tailored to snow
- Use this technique with particles!

Uncharted 2 had technique for projecting footprints, written by my colleague Carlos Gonzales
Specifically to project static sprites onto ground plane
Perhaps adapt? We could use projection technique, but modify it for arbitrary planes and dynamic images
Allow us to create realistic looking sand footprints that would flow and slide like ref footage!

Projected Particles



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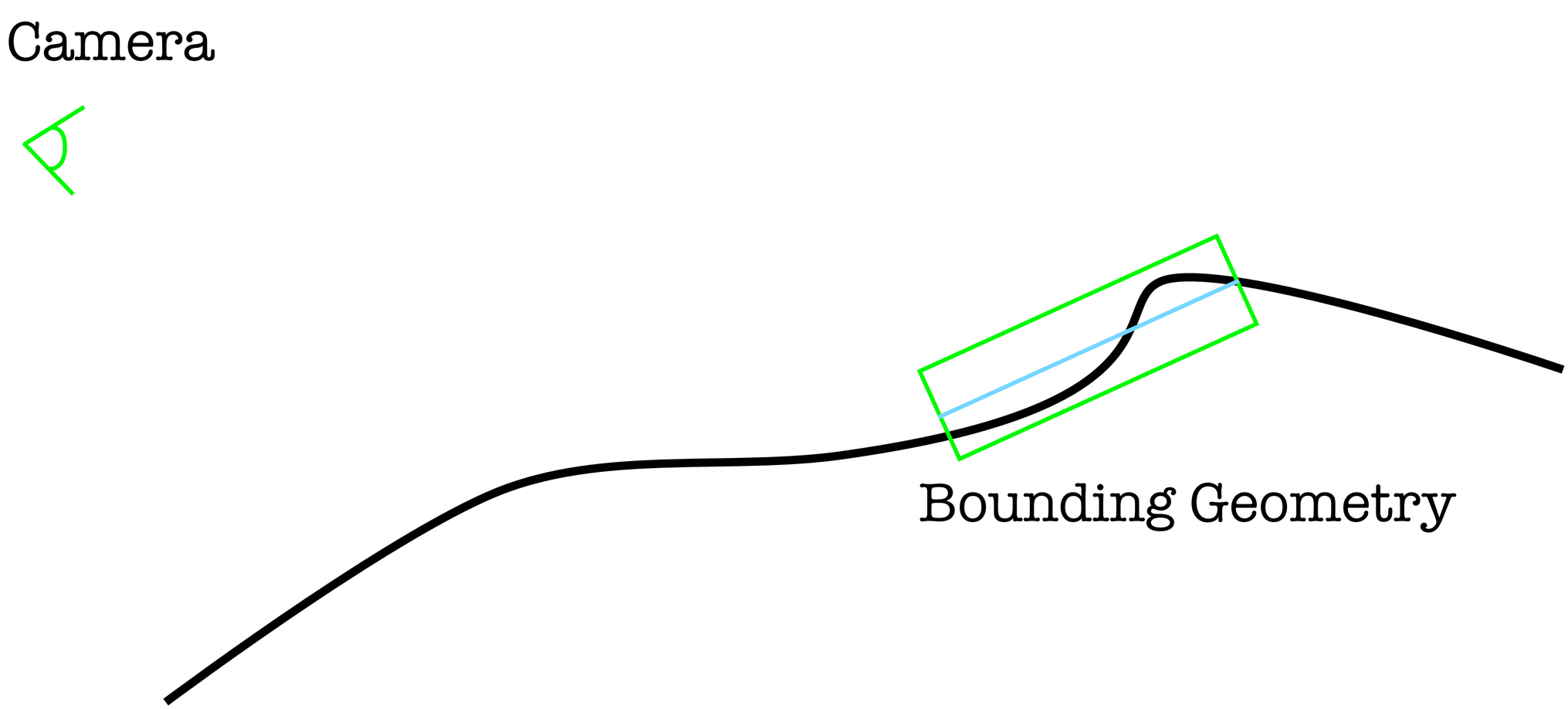
Intuition – project image onto plane
Draw bounding geom that covers screen area we want to draw
Each pixel, sample the depth buffer, calculate world position of the sample, and transform to the particle space
Particle space = projection space of the texture, normalized to the extents of the print particle
If it's within a specified dist of the plane, draw, else discard
Dist tolerance lets us wrap the surface a bit, if its not flat

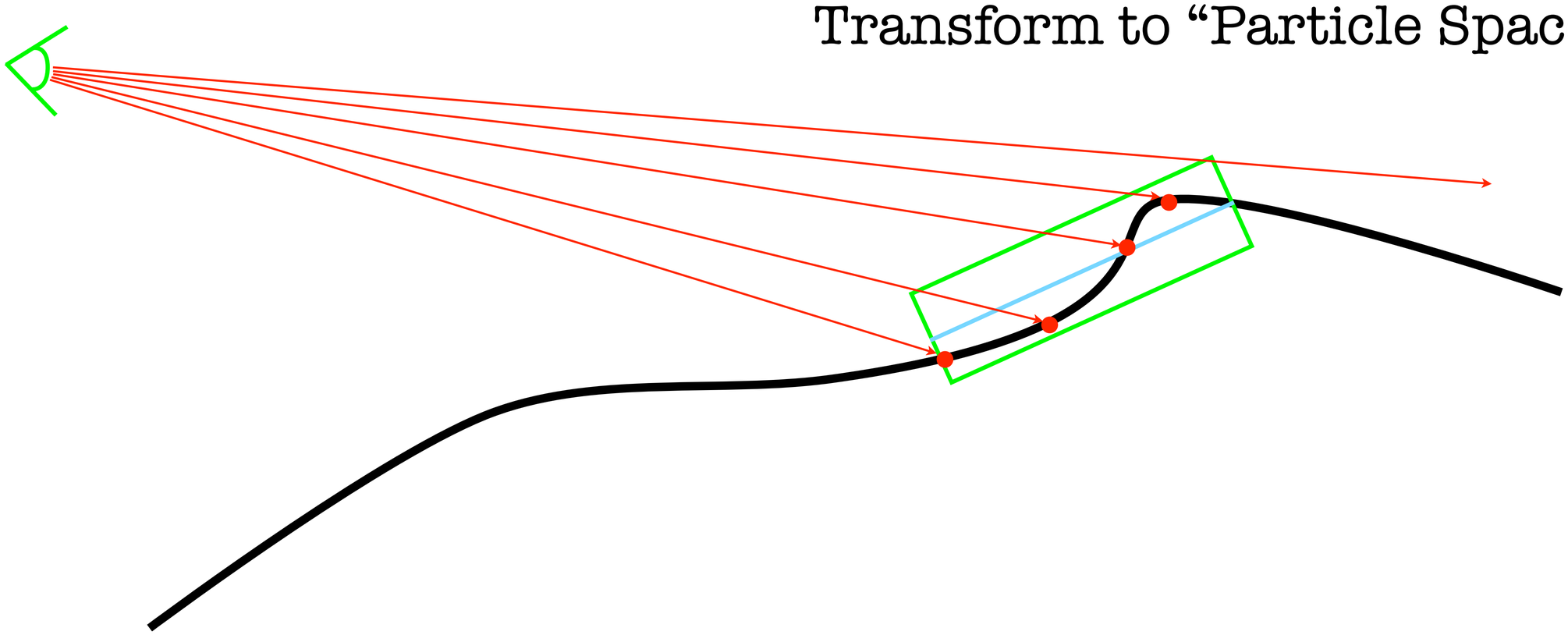
Projected Particles



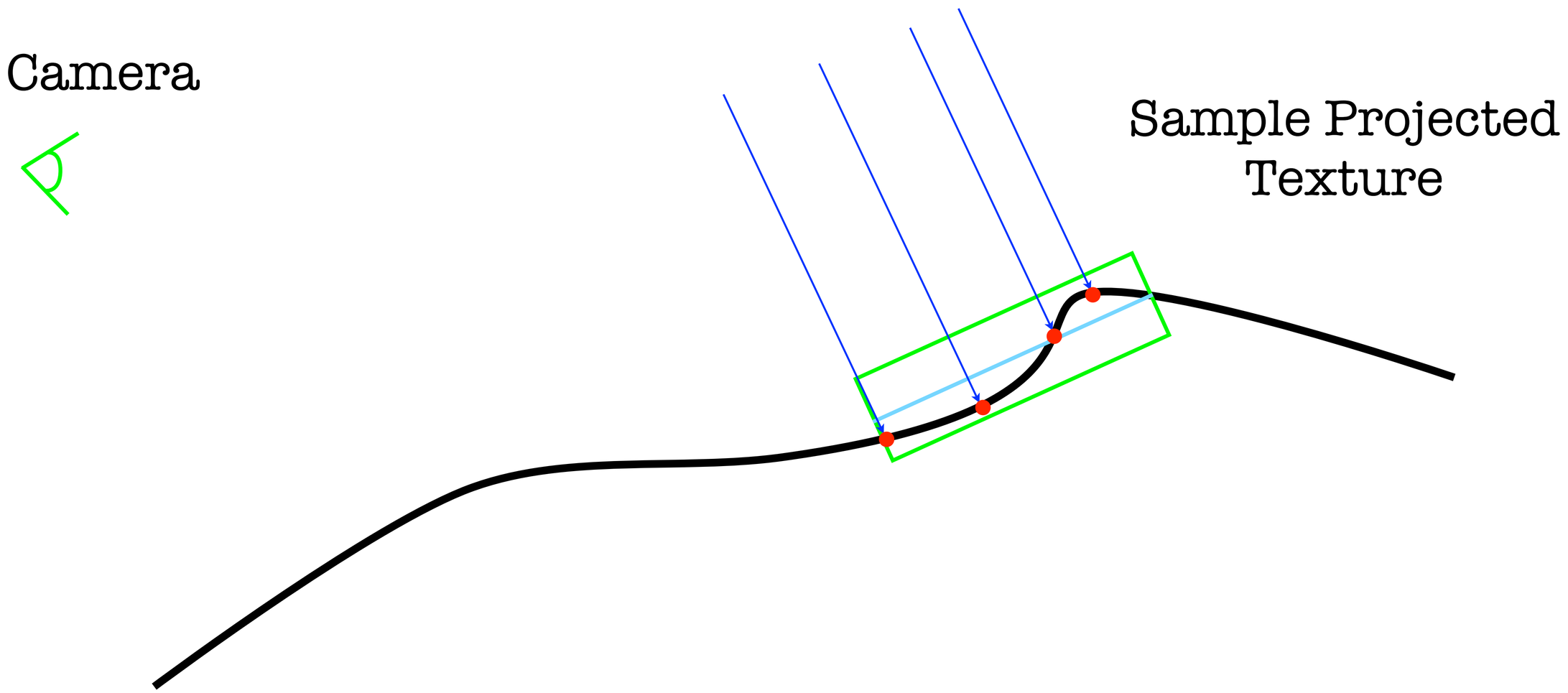
Projected Particles

Camera

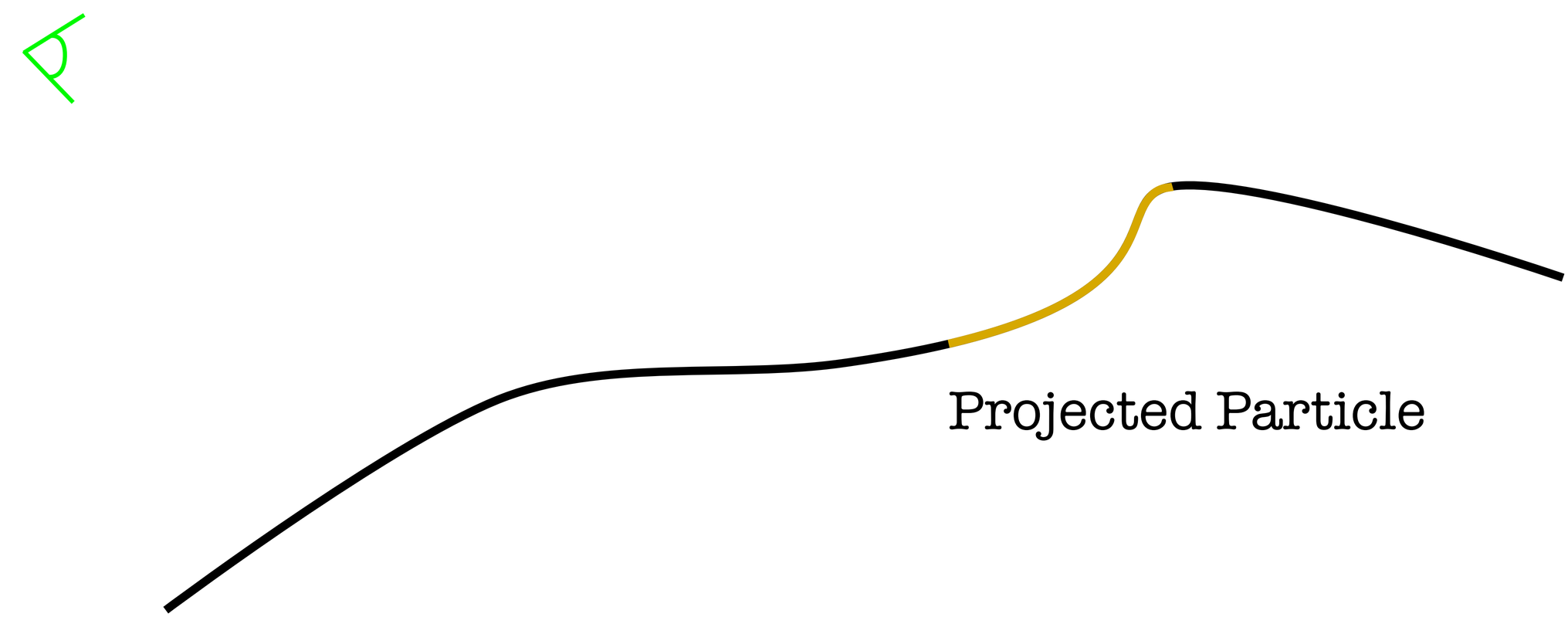
Sample Depth Buffer and
Transform to “Particle Space”



Projected Particles



Projected Particles



Particle Geometry

- Render a box bounding the area of the particle in xyz
- Box is just used to run screen space shader
- UVs of box not important to the shader

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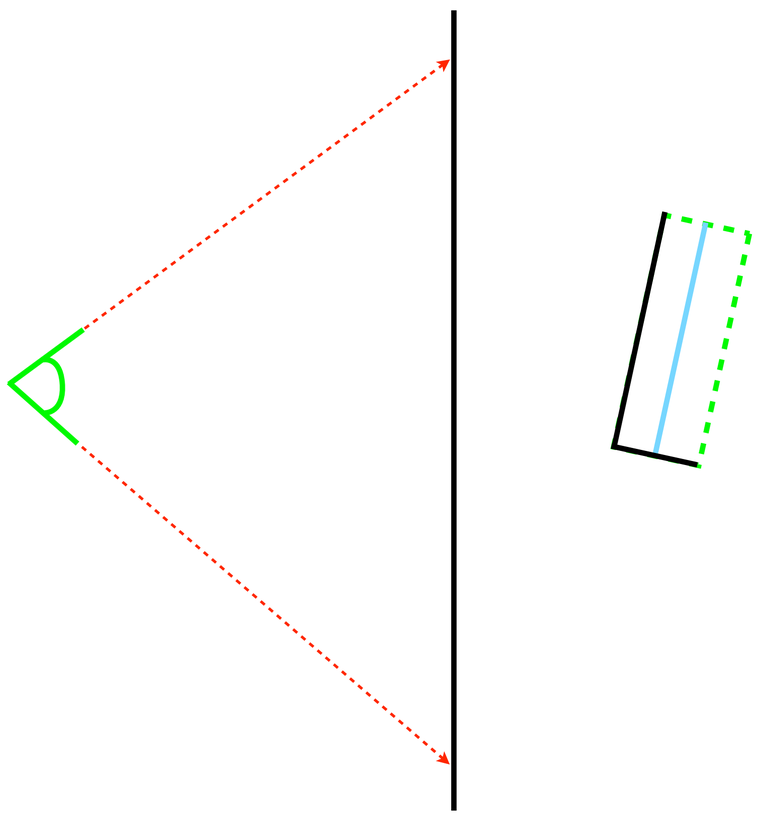
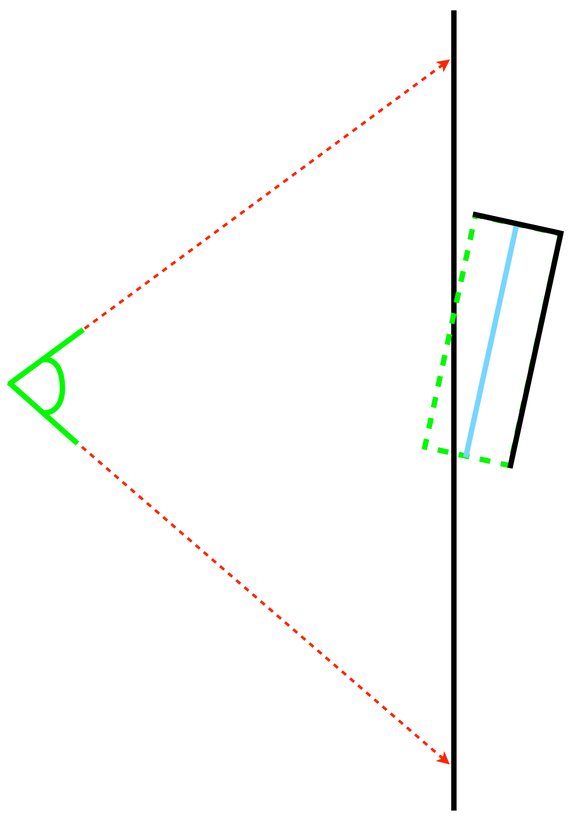
Render a box bounding the particle
Just to run the pixel shader, UV is not used

Particle Geometry



Cull back faces
ZTest enabled

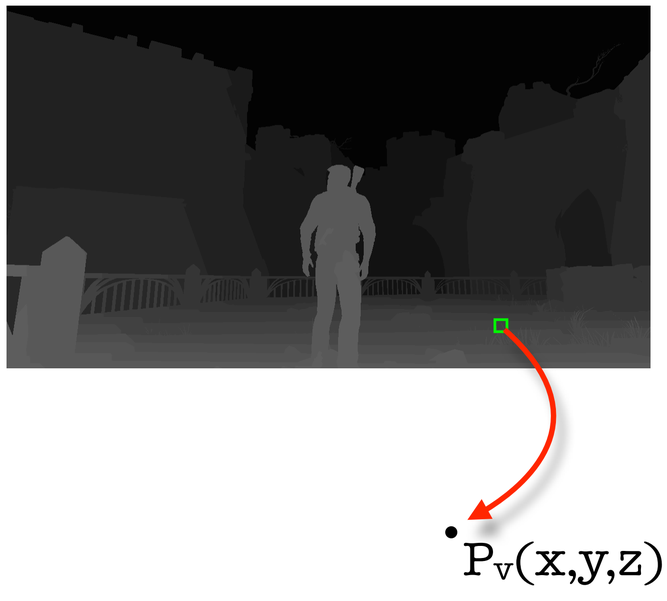
Particle Geometry



Cull front faces
ZTest disabled

Particle Projection

- Transform Depth to View



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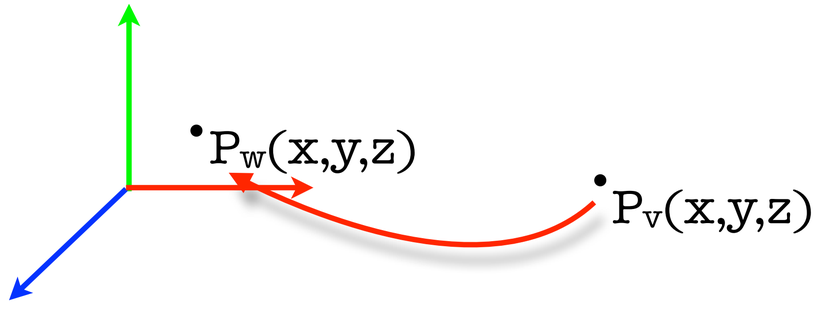
Particle space description

Particle Projection

- Transform Depth to View
- Transform View to World



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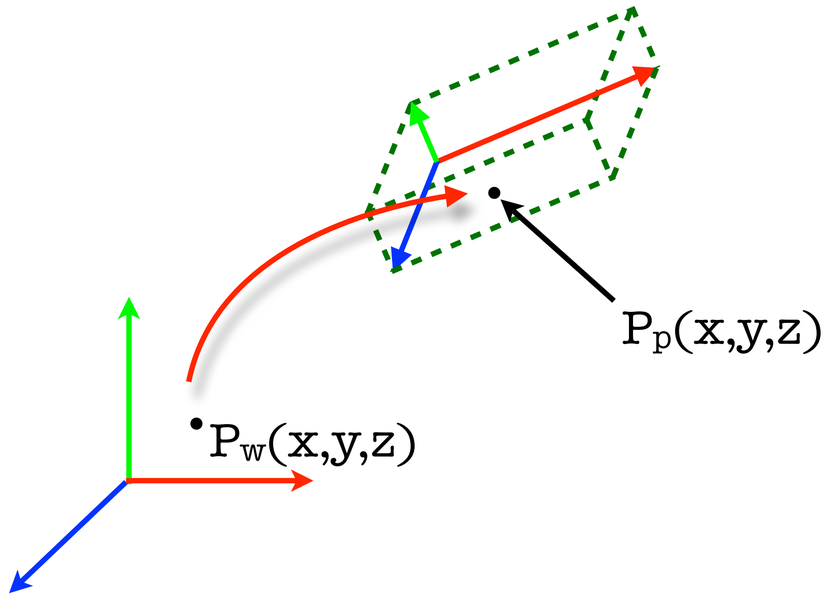
Particle space description

Particle Projection

- Transform Depth to View
- Transform View to World
- Transform World to Particle Space



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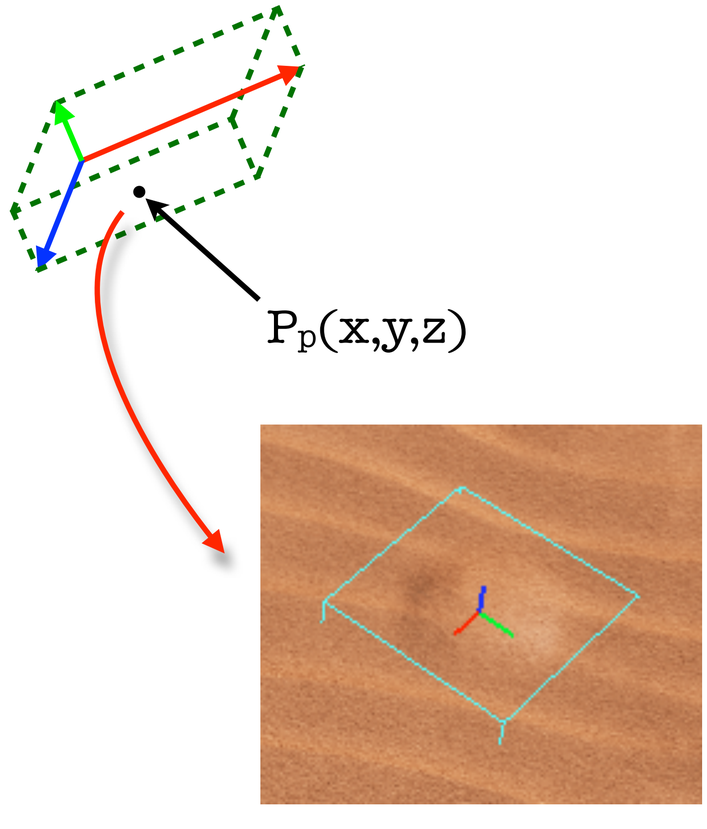
Particle space description

Particle Projection

- Transform Depth to View
- Transform View to World
- Transform World to Particle Space



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Particle space description

Transform Depth to World

- Transform screen pos (WPOS) to view space xy coord
- Sample depth buffer
- Calculate view z from depth value
- Undo perspective correction
  - pos = float3(xy * z, z)
- Transform from view to world

Transform World to Particle

- Tangent space vectors
- 2 additional vertex attributes
  - Origin (WS)
  - InvScale (inverse scale in XYZ)

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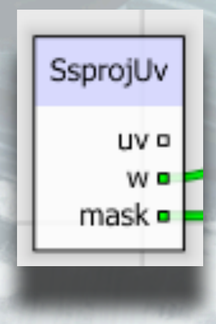
Required inputs
Origin of particle
Inv scale of particle

Transform World to Particle

- Subtract Origin from P_W
- Transform from WS to tangent space
- Scale coord with InvScale
- Result = xyz coordinates normalized to particle!

SSProj UV Node Outputs

- UV: XY coordinates
- W: Z coordinate
- Mask: 1 if xyz values are all in the range [0,1], 0 otherwise. Multiplied with alpha



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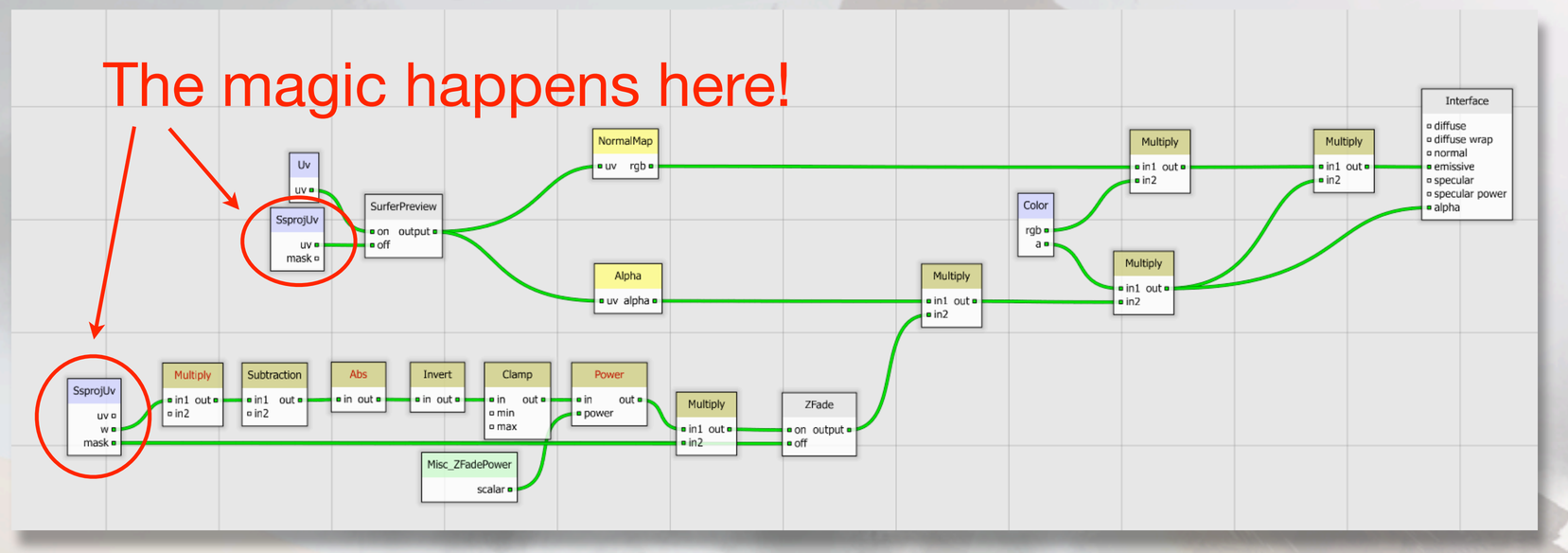
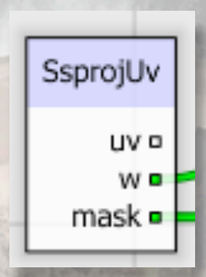
We put this functionality into 1 node!
XYZ coordinates are normalized to 0..1 within the projection space of the particle
Values can be outside the particle box
Z value useful if artist wants to calculate own alpha, for soft falloff, etc

Projection Shader





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Match BG lighting?

- U3 uses a deferred lighting technique
- Normals rendered to a buffer during the depth pass
- Used by SPU dynamic lighting code, resulting lighting used by main render pass

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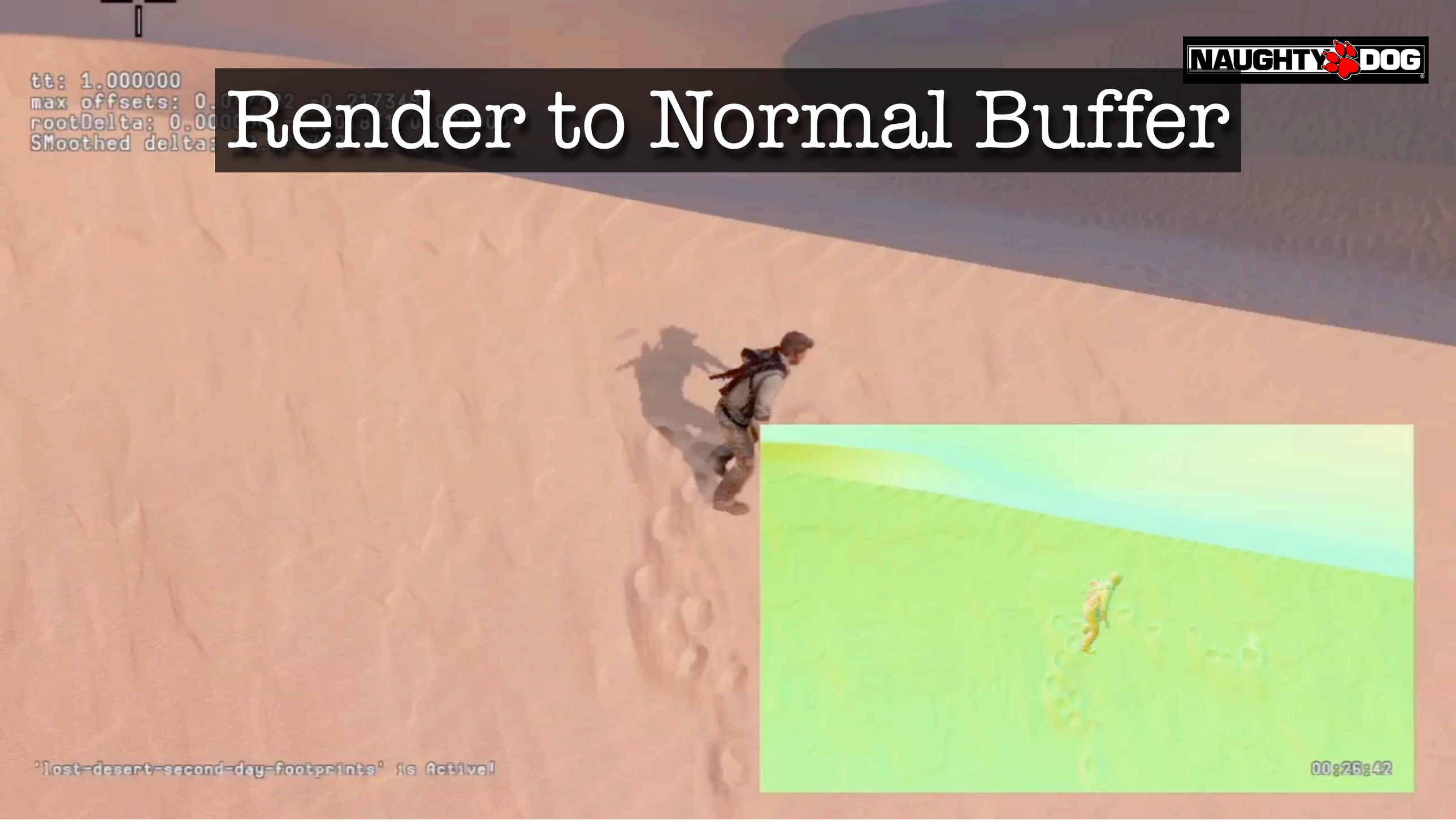
Particles use a simple lighting model, how can we match the background?
BG use deferred lighting with lots of dynamic lights run on SPU

Render to Normal Buffer



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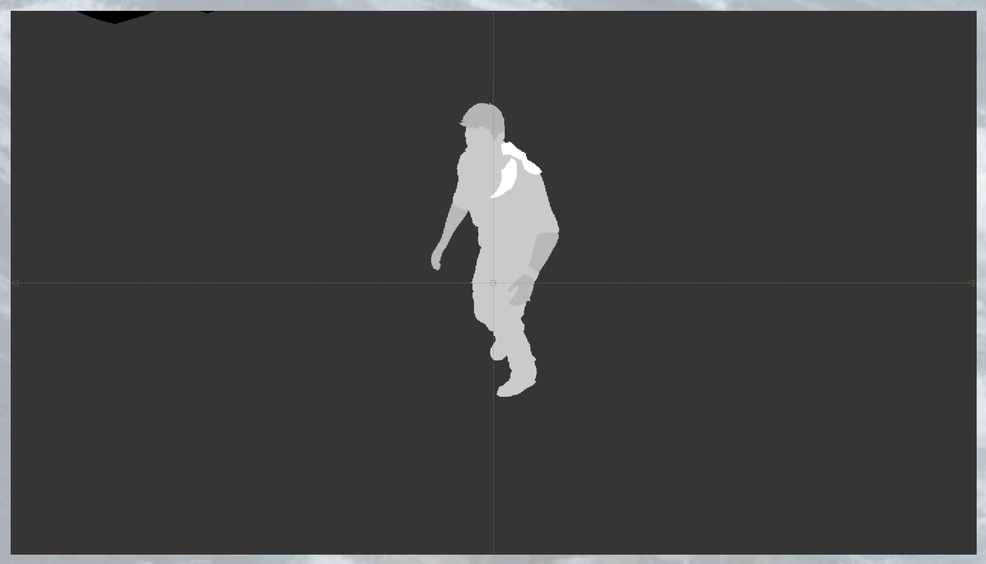
We can modify normal buffer with projected particles!
Allows dynamic alteration of backgrounds with seamless lighting

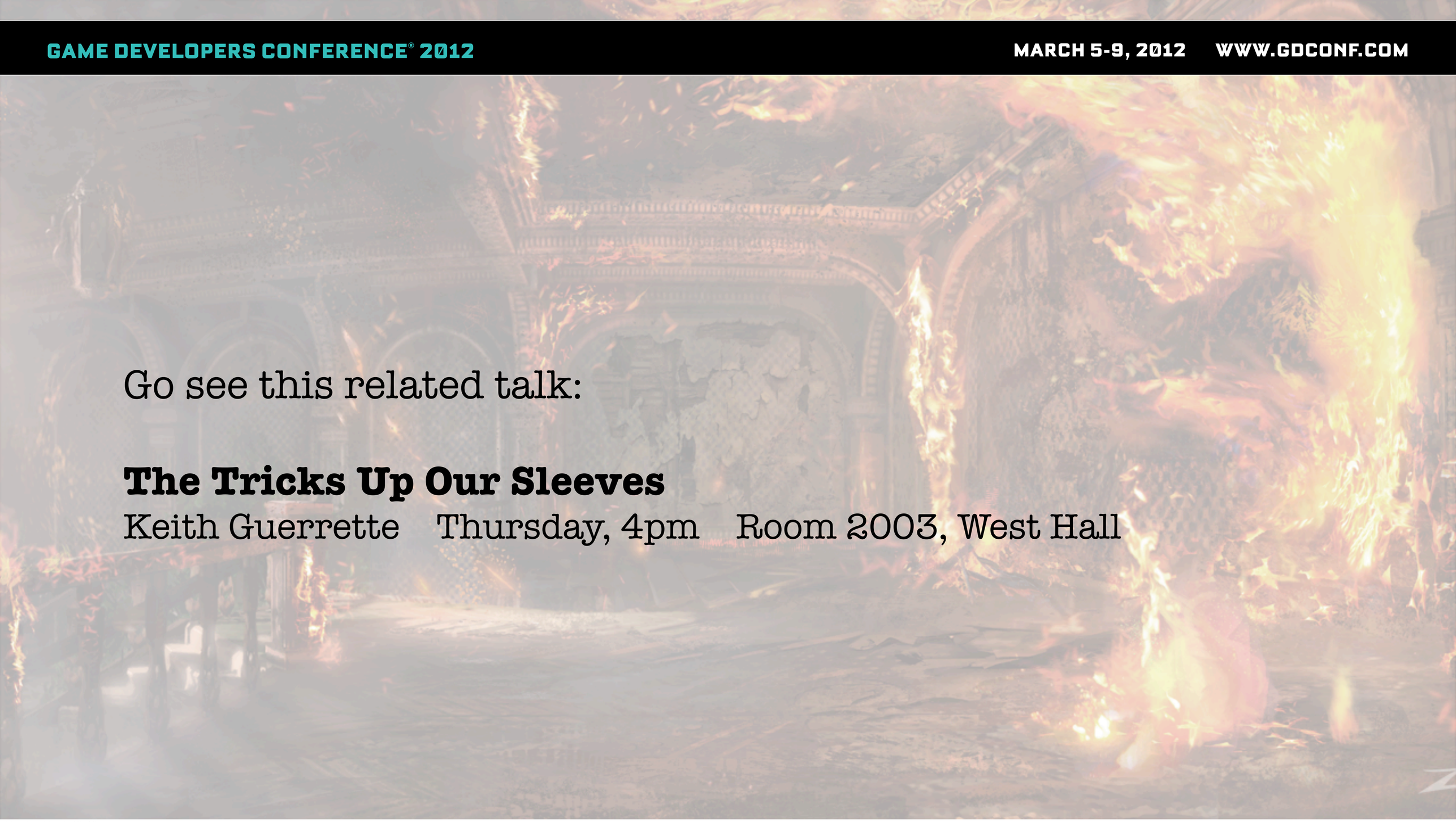
Stencil

Use stencil value to avoid drawing projected particles on FG objects!



Final Thoughts

- Quality is a result of iteration - so speed up iterations!
- Give flexibility to the artists
  - You will have to do some handholding but results are worth it
- Node based shader editors aren't so bad



Go see this related talk:

The Tricks Up Our Sleeves
Keith Guerrette Thursday, 4pm Room 2003, West Hall

Thanks

Doug Holder
Carlos Gonzalez
Keith Guerrette
Eben Cook
Mike Dudley
Iki Ikram
Ryan James
Sony WWS ATG
Lynn Soban

Questions?

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