Render the Possibilities

SIGGRAPH2016

THE **43RD** INTERNATIONAL
CONFERENCE AND **EXHIBITION** ON

Computer Graphics & Interactive Techniques

24-28 JULY

ANAHEIM, CALIFORNIA

Render the Possibilities
SIGGRAPH 2016
THE 43RD INTERNATIONAL CONFERENCE AND EXHIBITION ON
Computer Graphics & Interactive Techniques

Rendering Techniques of Final Fantasy XV

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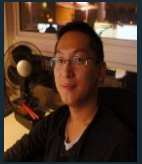
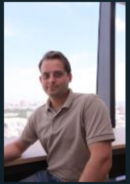
Authors

Sharif Elcott	Advanced Technology Division
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Other SESSIONS

ANGRY EFFECTS SALAD

Visual Effects of Final Fantasy XV: Concept, Environment, and Implementation

Monday, 25 July, 2-3:30 pm

BUILDING CHARACTER

Character Workflow of Final Fantasy XV

Tuesday, 26 July, 2-3:30 pm

BRAIN & BRAWN

Final Fantasy XV: Pulse and Traction of Characters

Tuesday, 26 July, 3:45-5:15 pm

PLAYING GOD

Environment Workflow of Final Fantasy XV

Wednesday, 27 July, 3:45-5:15 pm

ELECTRONIC THEATER

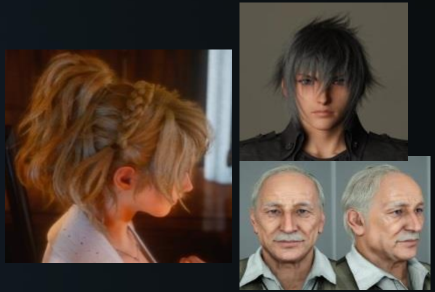
The Universe of Final Fantasy XV

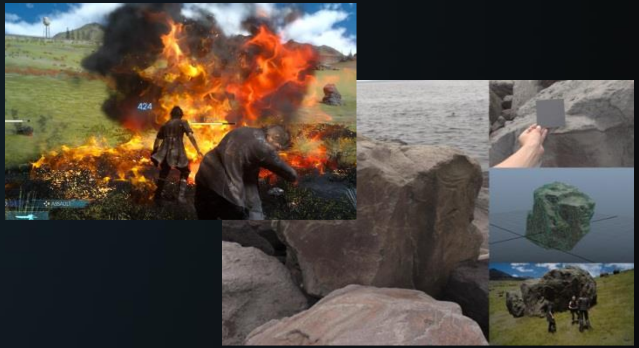
Mon, 25 July, 6-8 pm / Wed, 27 July, 8-10 pm

REAL-TIME LIVE

Real-Time Technologies of FINAL FANTASY XV Battles

Tuesday, 26 July, 5:30-7:15 pm





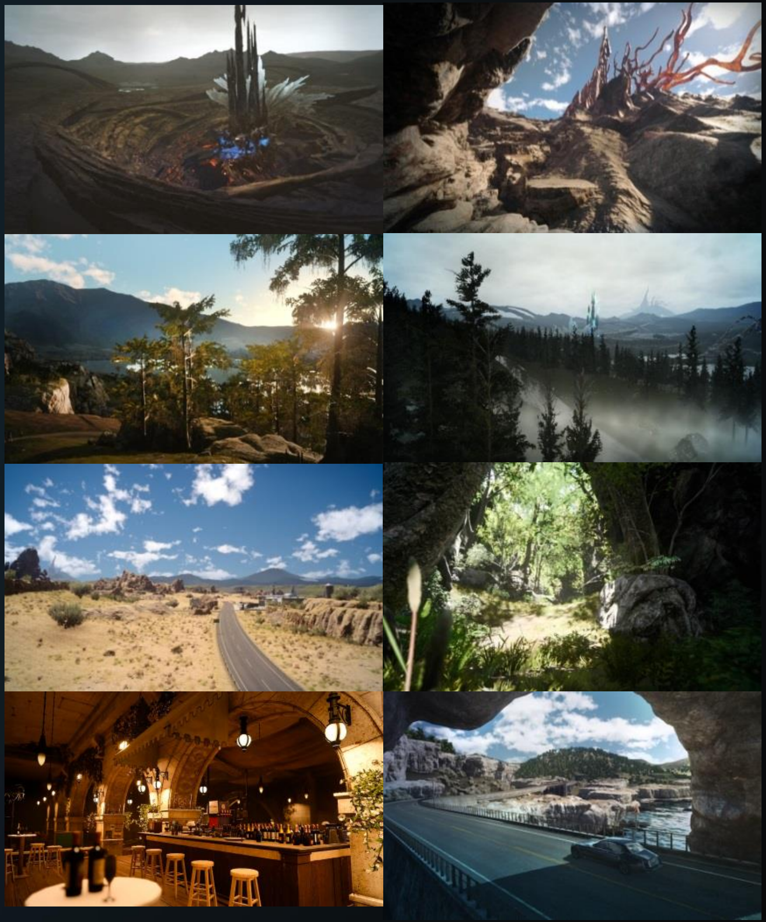
Final Fantasy XV

- Action role-playing game
- PlayStation4, XBoxOne
- Release date: Sept 30, 2016

- Demos
  - Episode Duscae
  - Platinum Demo

Final Fantasy XV

- The most “open-world” FF
  - Indoor & outdoor
  - Day/night cycles
  - Dynamic weather
  - Sky and weather are a big part of storytelling



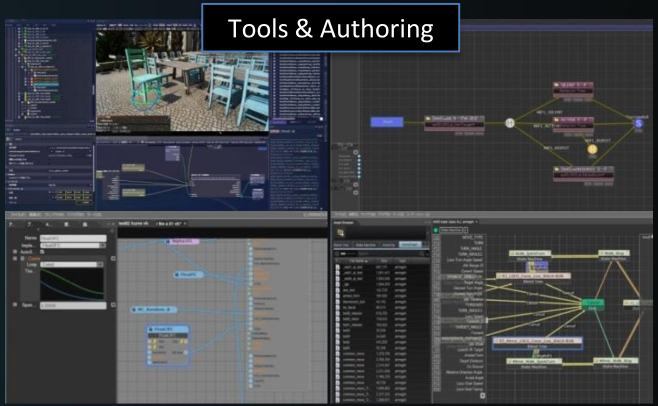

FINAL FANTASY XV
World of Wonder: ENV Footage

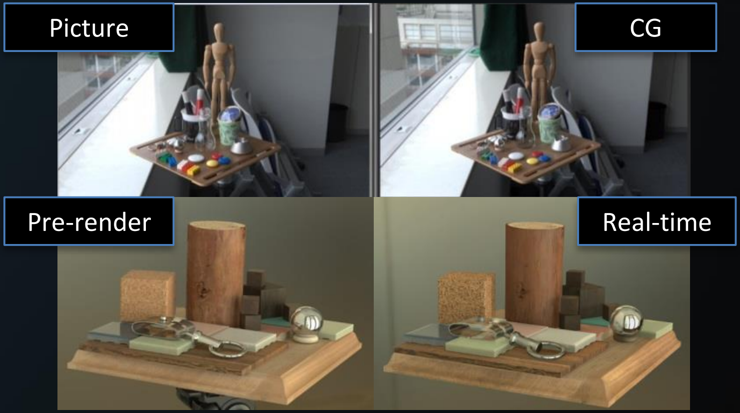
Agenda

- Basic Rendering
- Global Illumination
- Sky
- Weather

Basic features

- Modern AAA-class engine
- The usual suspects
  - Physically-Based Shading
  - Linear workflow
  - Deferred & forward
  - Tile-based light culling
  - IES lights
  - Cascaded Shadow maps
  - Temporal Antialiasing
  - Use of Async Compute
  - Node based authoring
  - etc.





Shading

- Physically-based BRDF model
  - Torrance-Sparrow BRDF
    - Normal distribution function = Trowbridge-Reitz (GGX)
    - Masking function = Schlick-Smith
    - Fresnel term = Schlick
  - Roughness/metallic control
  - Lambertian diffuse

$$f(\mathbf{l}, \mathbf{v}) = \frac{D(\mathbf{h})F(\mathbf{v}, \mathbf{h})G(\mathbf{l}, \mathbf{v}, \mathbf{h})}{4(\mathbf{n} \cdot \mathbf{l})(\mathbf{n} \cdot \mathbf{v})}$$

$$D_{GGX}(\mathbf{m}) = \frac{\alpha^2}{\pi((\mathbf{n} \cdot \mathbf{m})^2(\alpha^2 - 1) + 1)^2}$$

Shading

Deferred
- Basic BRDF material

\+

Forward
- Transparent
- Special materials

Tricks for special materials

- Eyes: D=diffuse, F=second specular
- Car paint: D=diffuse, F=extra layers (flake/clear coat)
- Skin: D=diffuse+spec(2 RTs), blur diffuse, F=combine
- Hair: D=depth/normal, F=all shading

etc.

G-buffer

G-buffer layout for basic BRDF material

- Used to identify BRDF etc.
- flags for specific processes

	R	G	B	A	
F32_S8	depth				stencil
RT0	compressed normal			roughness	
RT1	albedo			occlusion	
RT2	metallic	-	-	specular	

Used to support special materials (backscatter color, hue shift, etc.)

Agenda

- Basic Rendering
- Global Illumination
  - Indirect Diffuse
  - Specular Reflection
- Sky
- Weather

Lighting: Requirements

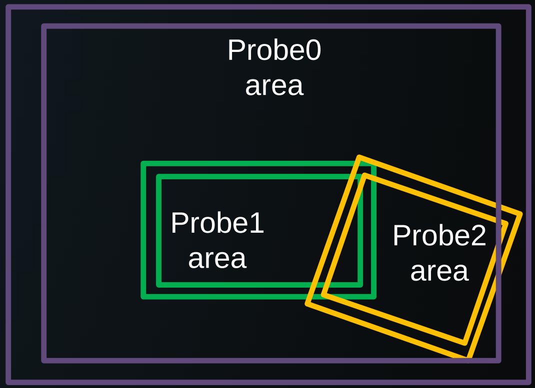
- Seamless indoor/outdoor transitions
- Moving vehicles (e.g. train cars)
- Time of Day
- Dynamic Weather

- Cannot rely only on static baked lighting data
- Data storage requirements

➡ Hybrid GI strategy based on both dynamic/static data.

Indirect Diffuse: Local probe

- We use grids of local light probes
  - Can be placed to fit navigation meshes or heightmaps automatically
- Organized into hierarchies of grids
  - overlapping light probe grids
  - $w_1 C_1 + \cdots + w_N C_N + (1 - (w_1 + \cdots + w_N))K$
    - w_i:weights, C_i: diffuse by probe, K: diffuse by sky
  - Controls of fade-out regions
  - Controls of blending priorities



Indirect Diffuse: Local probe

A given probe grid can have either:

- Precomputed Radiance Transfer (PRT)
  - Sky occlusion
  - fully outdoor scenarios
- Irradiance Volumes (IV)
  - Diffuse lighting from static local lights
  - fully indoor scenarios
- Both
  - outdoor towns, rooms with windows, etc...

Indirect Diffuse: Local probe

- PRT transfer matrices calculated by in-house path tracer
  - Matrix of SH coefficients (order 3 SH)
- Both IV and PRT data stored together
  - IV (order 3 SH) is just an additional row to the PRT transfer matrix

At runtime, we light the probes:

(sky SH) * (PRT transfer matrix) + (irradiance SH)

Run time data

Baked data

For each 9 coefficients of SH
For each RGB channel.

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SQUARE ENIX

Indirect Diffuse: Moving probe

- Handling moving environments
  - Trains and airships have probes inside.
  - The environment itself can move and rotate relative to the outside

Probes can be attached to train wagons

Solution:

Bake probes with local environment
Rotate SH data at run time based on relative orientation to the sky.

Indirect Diffuse: Local occlusion

- Screenspace Ambient Occlusion
  - Custom algorithm created in collaboration with the LABS group [Michels et al. 2015]
  - Half-res AO/blur with upsampling
  - 8 samples
  - Use temporal reprojection
- Analytical AO
  - "AO spheres" attached to foliage & heroes
  - Apply analytical AO in tiled fashion
    - less than 1ms

Indirect Diffuse: Local occlusion

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  - "AO spheres" attached to foliage & heroes
  - Apply analytical AO in tiled fashion
    - less than 1ms

Indirect Diffuse: Dynamic light bounce ?

- We disabled RSM(Reflective Shadow Map)-based dynamic GI.
  - Light Propagation Volumes [Kaplanyan 2010]
  - Virtual Spherical Gaussian Lights [Tokuyoshi 2015]

- Completely dynamic, but RSMs were expensive for our game.
  - Lots of high-poly scenes in our game.
- Instead, we use computational resources for rendering dynamic natural environment like sky/clouds.

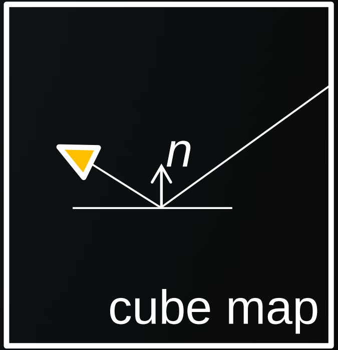
Agenda

- Basic Rendering
- Global Illumination
  - Indirect Diffuse
  - Specular Reflection
- Sky
- Weather

Specular Reflection

Tiered system

- Global cubemap (sky box)
  - Updated by time of day and weather
  - Filtering is spread over multiple frames
- Local cubemaps with parallax correction
  - We want to support time-of-day change
- Screenspace reflection [Wronski 2014, Valient 2014]
  - Classic ray march
  - Roughness-based bilateral blur (half-res)& upsample



Specular Reflection

- Problems with classic local cubemaps
  - Static. How to handle time-of-day / weather changes?
  - Baking probes at runtime is too expensive.
- Typical workaround:
  - 1. Re-light cubemap at runtime using a mini G-buffer [McAuley 2015]
    - Still expensive
  - 2. Blend between probes baked in different time/weathers
    - Blending artifacts

Specular Reflection

Our solution

- Split into 3 components:
  - 1. Sky pixel
  - 2. Pixel not affected by time of day (local lights / emissive)
  - 3. Pixel affected by time of day (e.g. sun and sky)
- Fast to evaluate
- Less memory footprint.

Specular Reflection

- 1st component: Sky Mask
  - At bake time
    - Generate mask that identifies “sky” pixels
  - At runtime
    - shaders fall back to the dynamic skybox based on this mask
    - reflection vectors that hit the sky see moving clouds!

Specular Reflection

- 2nd component: Baked static lighting
  - At bake time
    - Turn off : sun, skylight, fog, atmospheric scattering, etc..
    - Do a cubemap capture & filter
  - At runtime
    - Use the map as-is, with a roughness-based lookup
    - same as in [Valient 2014]

Specular Reflection

- 3rd component = Sun and Sky
  - At bake time
    - Keep all lights ON and render
    - Substract previous “local lighting” to get a cubemap of the scene as lit by only the sun and sky
    - Sky color (constant term of sky SH) divided out before saved
  - At runtime
    - Sky color for the current frame is multiplied back in

Specular Reflection

- Summary

dynamic data

Constant term of the SH-projected sky box

Sky box color

$$\text{Reflection} = (S_n D_r + L)(1 - M) + K_r M$$

static data

Normalized baked sky data

Baked local light data

Baked sky mask

Specular Reflection

- Data storage
  - If we implement naïvely, we would need 7 channels
    - S_n : sun and sky lighting, RGB (HDR)
    - L : baked local light data, RGB (HDR)
    - M : sky mask, float {0, 1}
  - Of course, we will compress

Specular Reflection

Key idea

- Assume that S_n and L have roughly similar color.

$$\text{Reflection} = \boxed{(S_n D_r + L)}(1 - M) + K_r M$$

$$\boxed{S_n(D_r + R)} \quad \text{with } R = L/S_n$$

We approximate the ratio R with a single channel.

Note that S_n can be zero indoor, and L can be zero outdoor.

Specular Reflection

Solution

1. Pick S or L as the key color

$$
\begin{aligned}
\text{if}(S = 0 \text{ and } L = 0) \qquad & key = 0, 0, 0 \\
& R = 0 \\
\text{else if}(S \geq L) \qquad & key = S \\
& R = lum(L)/lum(S) \\
\text{else} \qquad & key = L \\
& R = lum(S)/lum(L)
\end{aligned}
$$

Specular Reflection

Solution

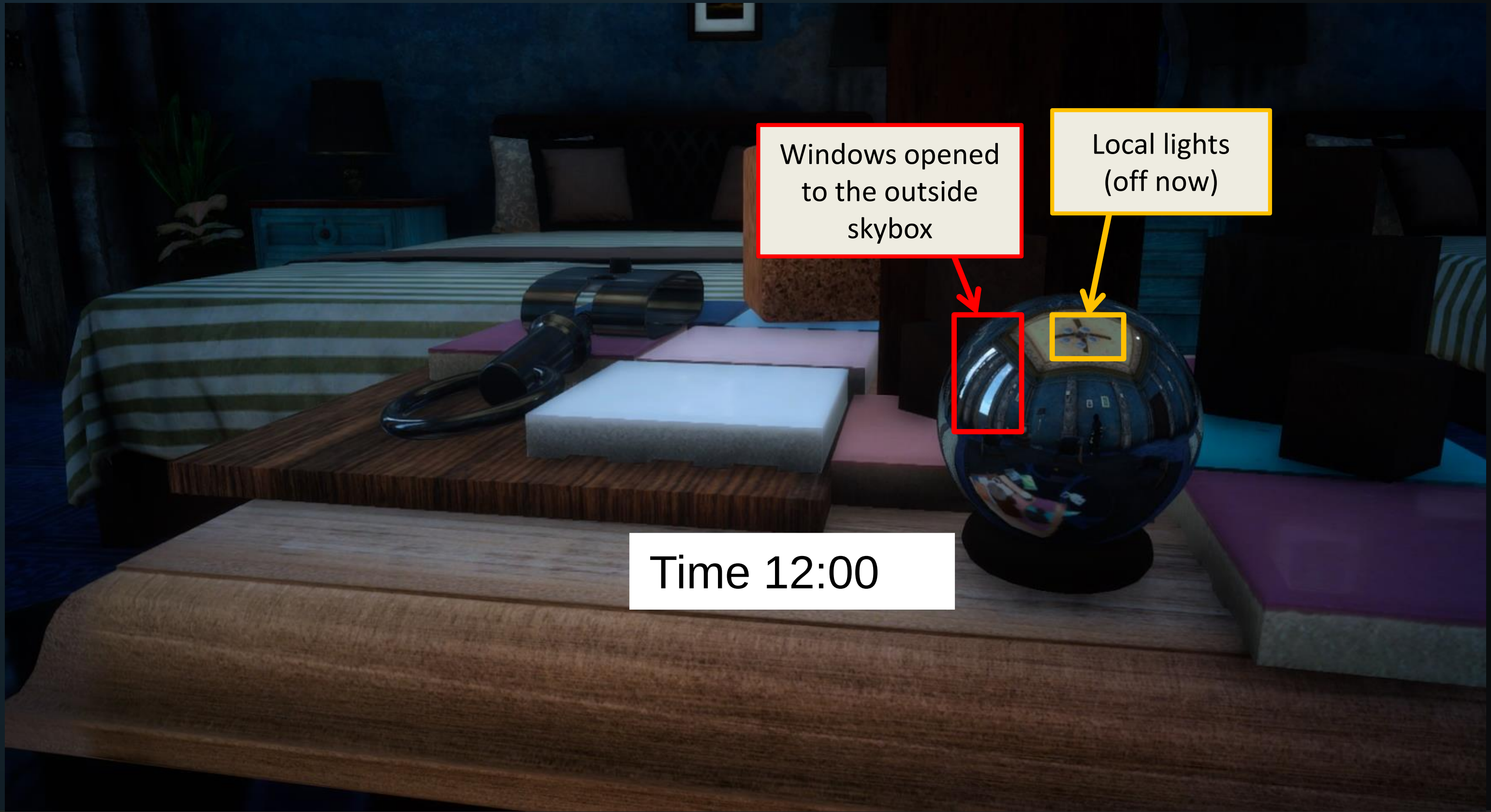
1. Pick S or L as the key color
2. Disambiguate at runtime using [0-2] range

$$
\begin{aligned}
\text{if}(S = 0 \text{ and } L = 0) \quad & key = 0,0,0 \\
& R' = 0 \\
\text{else if}(S \geq L) \quad & key = S \\
& R' = lum(L)/lum(S) \\
\text{else} \quad & key = L \\
& R' = 2 - lum(S)/lum(L)
\end{aligned}
$$

If $R' \in [0,1]$ then the key is S and $R = R'$.

If $R' \in [1,2]$ then the key is L and $R = 2 - R'$.

Specular Reflection: results



Specular Reflection: results

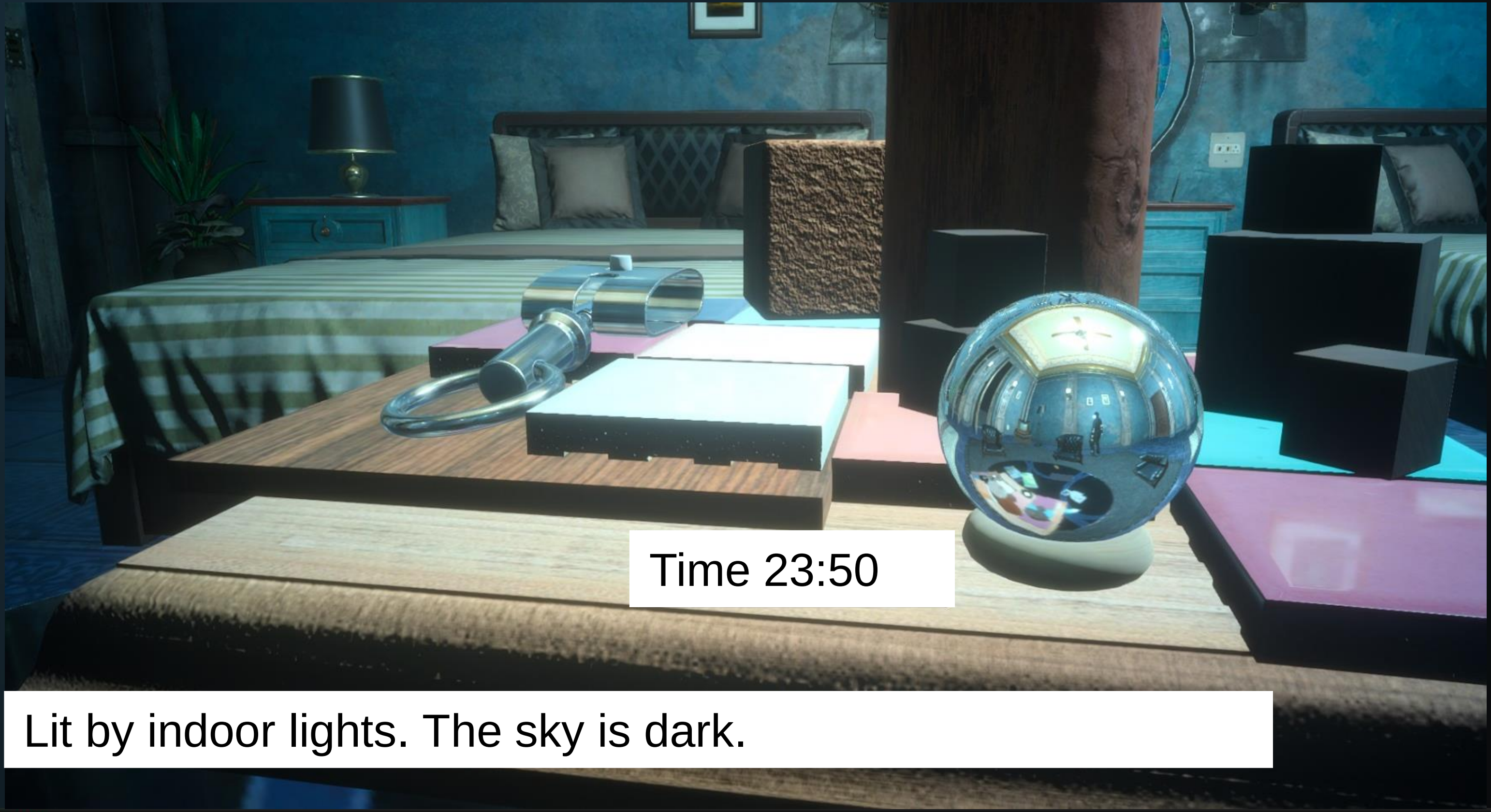
Specular Reflection: results

Specular Reflection: results

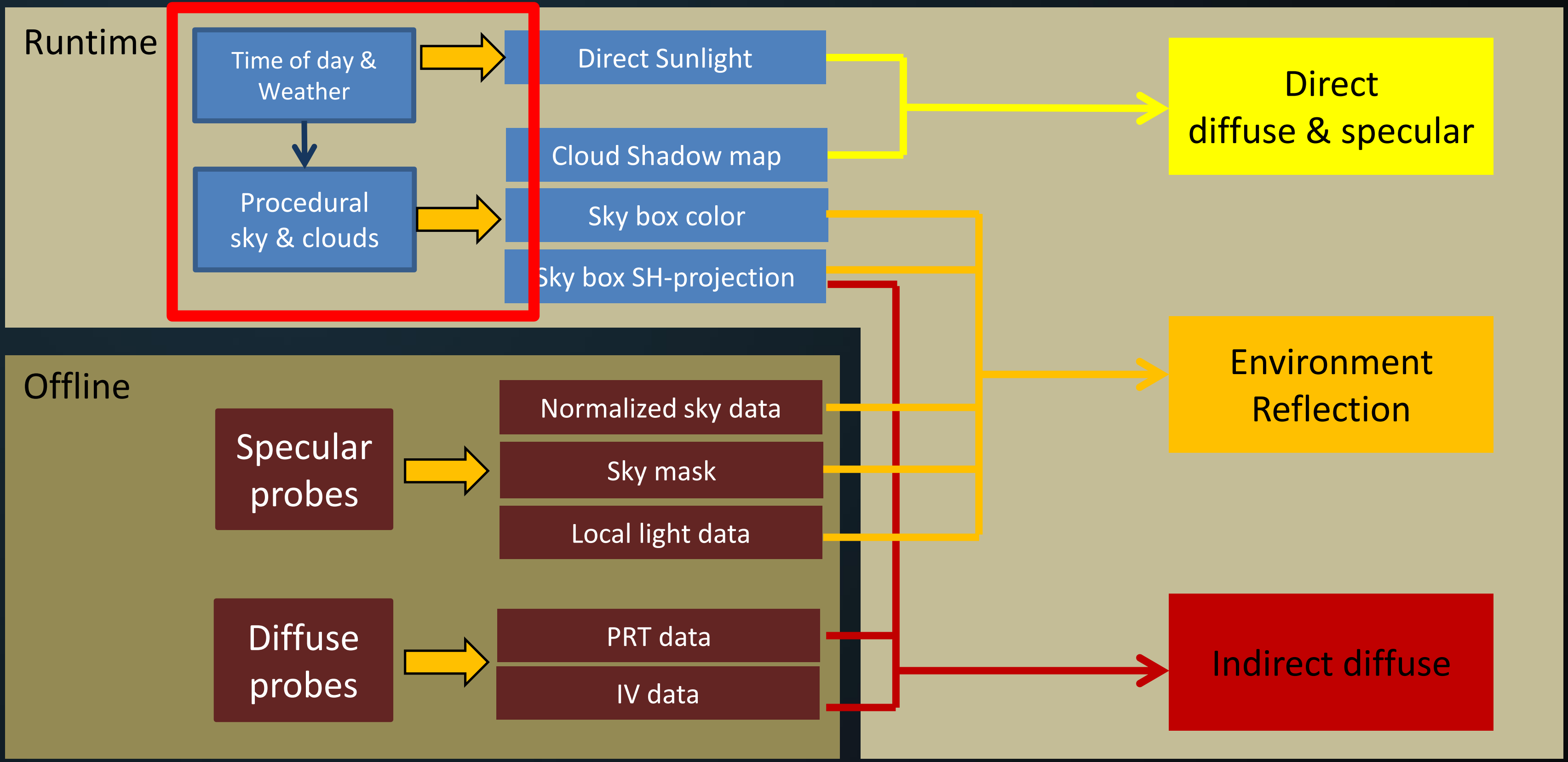
Time 19:20

Sunset. The scene is still lit by sky. Indoor lights switched on.

Specular Reflection: results



Summary

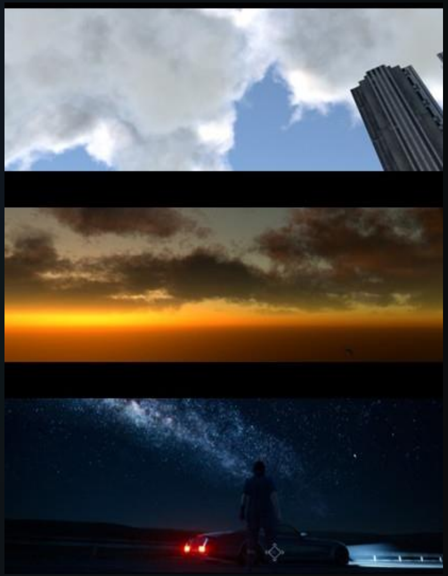

Runtime
Time of day & Weather
Procedural sky & clouds
Direct Sunlight
Cloud Shadow map
Sky box color
Sky box SH-projection
Offline
Specular probes
Diffuse probes
Normalized sky data
Sky mask
Local light data
PRT data
IV data
Direct diffuse & specular
Environment Reflection
Indirect diffuse

Agenda

- Basic Rendering
- Global Illumination
- Sky
  - Sky
  - Atmospheric Scattering
  - Clouds
  - Sky Cubemap
- Weather

Sky: Requirements

- Dramatic changes in atmosphere
- Linked with lighting and weather
- Quick but smooth transitions
  - from a cloudy afternoon to a rainy evening
  - from a clear starry sky to a red dawn
- Artist-Directable



Approach

- Generate the whole sky procedurally
  - Sun
  - Stars
  - Moon
  - Clouds
  - Atmospheric scattering

Sky Rendering

- Layers of sky:
  - Celestial objects
    - Milky way: on a cylindrical surface
    - Small stars: repeated textures
    - Large stars: billboards, instanced
    - Moon
    - Sun
  - Clouds + Atmospheric scattering (sky)
  - Atmospheric scattering (aerial perspective, fog to objects)

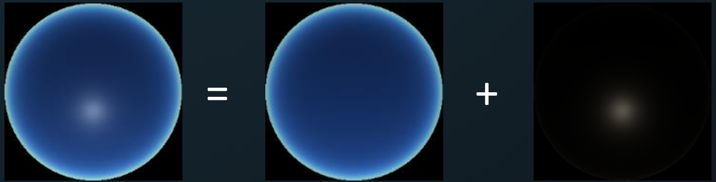
Atmospheric Scattering

- Standard models in games:
  - Single scattering model [Hoffman, Preetham, 2002]
    - + Fog can be rendered with the sky
    - - No twilight. Completely dark after sunset.
    - - Unintuitive artistic controls.
  - Precomputation/Analytical model [Bruneton, 2008], [Preetham, 1999], [Hosek, 2012]
    - Better artistic controls.
    - Didn’t match our reference photo well enough.

      -- we chose this model, but made static data on our own.

Atmospheric Scattering (Sky)

- Strategy: precomputed approach
  - Combine of LUTs (Lookup tables) and Rayleigh/Mie scattering function
  - Sky $= LutR(\theta,\gamma) * phaseR(\mu) + LutM(\theta,\gamma) * phaseM(\mu, g)$
    - θ: sun-zenith angle, γ: view-zenith angle, μ: angle from the sun
    - $phaseR = 1 + \cos^2 \mu$, (constants omitted for simplicity)
    - $phaseM = \frac{1-g^2}{2+g^2} * phaseR * (1 + g^2 - 2g\cos\mu)^{-1.5}$, g: ”haziness” in [0,1)



sky “Rayleigh part” “Mie part”

Atmospheric Scattering (Sky)

- Generate LUTs offline
  - A least squares fitting
  - Ray-trace sky (inscatter) based on real sky database.

- We dropped: High level view of sky, Earth’ shadow, etc.
  - Instead, we use the simple sky formula/LUTs.
  - but it was enough for our game.

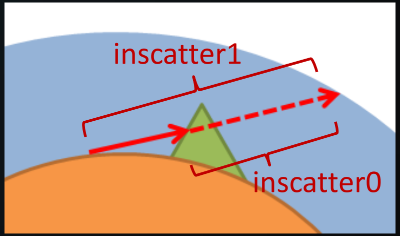
- Special case: Overcast sky
  - It uses different model [ISO 2004]
  - So we ended up mixing two models.

$\frac{1+2\sin\gamma}{3} * L_{zoc}$, L_{zoc}: zenith luminance

Atmospheric Scattering (Aerial perspective)

- Aerial perspective
  - *(inscatter color) + (transmittance) * (object color)*
- Transmittance: Beer's law
  - *(transmittance) = exp(-a*distance)*
- Inscatter color
  - (above pic) Bluish color addition in the distance.
  - In theory, inscatter is diff of sky colors at two points

    inscatter1 – inscatter0
  - We cannot get inscatter0 from our sky LUTs.
    - We made different LUTs.



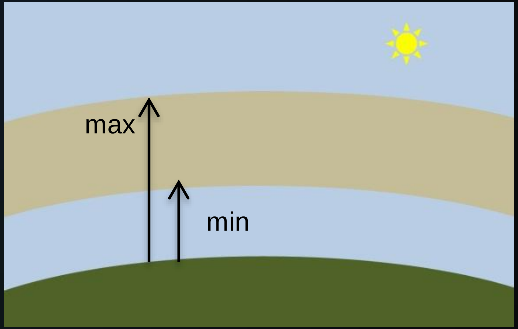
Atmospheric Scattering (Aerial perspective)

- Inscatter for aerial perspective
  - Inscatter only in horizontal direction.
  - Incatter is a combination of:
    - Mid-ground LUTs and a background LUT , for each Rayleigh/Mie component.
    - LUTs are combined with B-spline basis functions.
  - Background LUT is horizon part of sky LUT.
  - Designers can tint mid-ground color.

Clouds

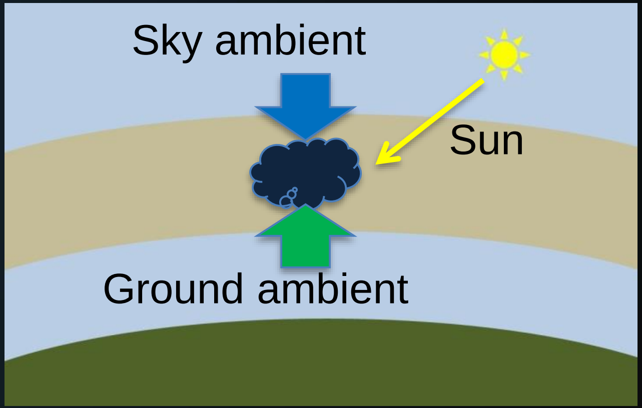
Clouds: Modeling

- Range
  - Above the camera position
  - Within user-defined range (altitude min/max, horizontal radius)
- Density Function
  - Combination of noise with 7 octaves
    - Different amplitude/animation speed for each.
    - Lowest octave -> rough cloud shape.
    - 2 lowest octaves -> rough shape animation
    - Higher octaves -> details.
  - Noise is obtained by sampling a small 3d texture.
  - Lots of parameters exposed to designers to make variation.



Clouds: Lighting

- Light clouds by raymarching
  - Three light sources:
    - Direct light from sun/moon
    - ambient from above (sky)
    - ambient from below (ground).

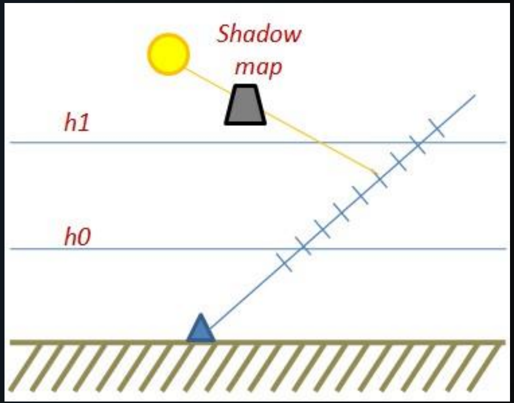


- Cloud opacity
  - is also calculated along with raymarching.
  - in order to blend the clouds with the sky dome.

- 4 results are packed into a RGBA8 texture.

Clouds: Lighting

- Direct light from sun/moon
  - Ray march with single scattering model.
  - We don’t use the 2nd ray march to the sun
  - Instead, we use *extinction transmittance map*
    - how much the light reaches the sample [Gautron, et al. 2011]



- Ambient is analytically computed
  - Integral over hemisphere assuming that the density is constant.

Clouds: Lighting

- Mie Scattering
  - Scattering phase function is factored out from the ray march.
  - Phase function gives directionality to the lighting.
    - Clouds close to the sun are brighter

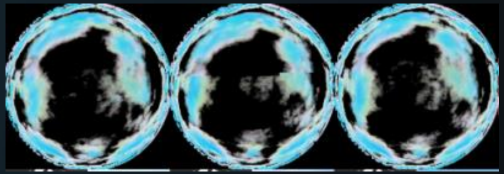
Clouds: Shadow

- ETM (Extinction Transmittance Maps)
  [Gautron, et al. 2011]
  – Clouds' self shadow
  – Shadow on the surface

- Transmittance curve along sun ray.
- A curve is encoded into:
  – 4 values using DCT (Discrete Cosine Transformation)
  – 2 values for start/end point of the curve
- These values are packed into 2 textures.

Clouds: Implementation

- Data storage
  - Raymarching results
    - 1536x1536, RGBA8 texture x3

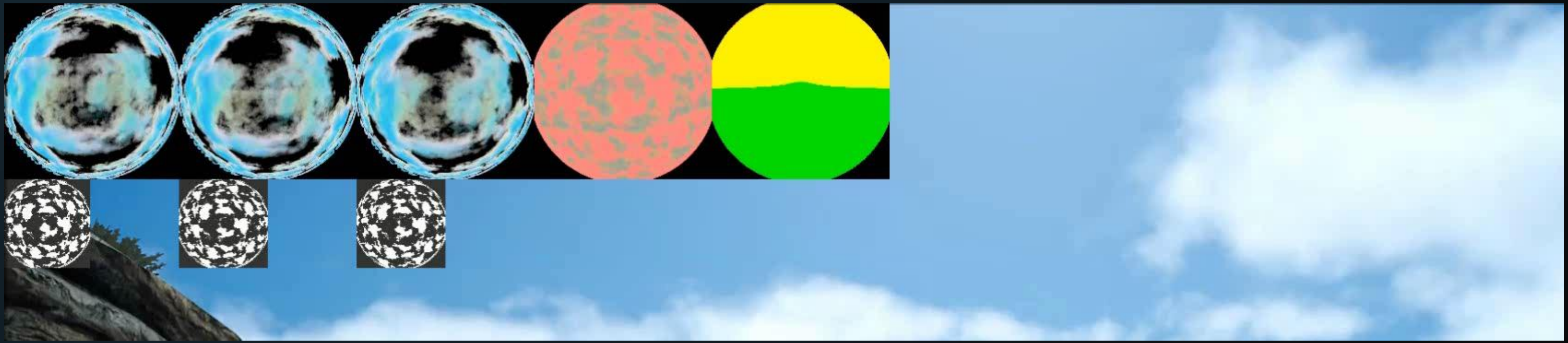


  - ETM
    - 512x512, RGBA8 texture
    - 512x512, RG16 texture

  - Shadow map for ground
    - 512x512, R8 texture x3

Clouds: Implementation

- We amortize the cost across several frames.
  - Raymarching : sky dome is split into 64 slices. 1 slice update/ frame.
  - ETMs for 4 frames.
  - Shadow map for ground.
- Async compute



Clouds: Sky dome

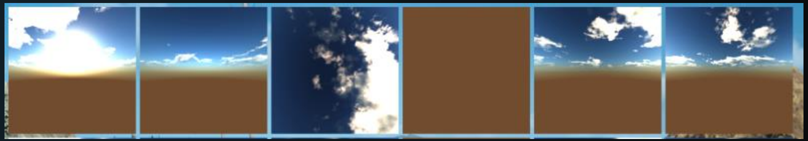
- Project clouds onto sky dome:
  - Cross-fade two cloud raymarch results over time
    - While the other one is being updated.
  - Wind Animation

Clouds: Wind

- Wind animation
  - 7 different animation speed in density function.
    - Choose dominant speed.
  - Assume clouds travel at a given fixed height.
  - Take into account perspective
    - Far clouds travels at a slower pace
    - Aerial perspective
- Animate cloud shadow in the same way

Sky Cubemap

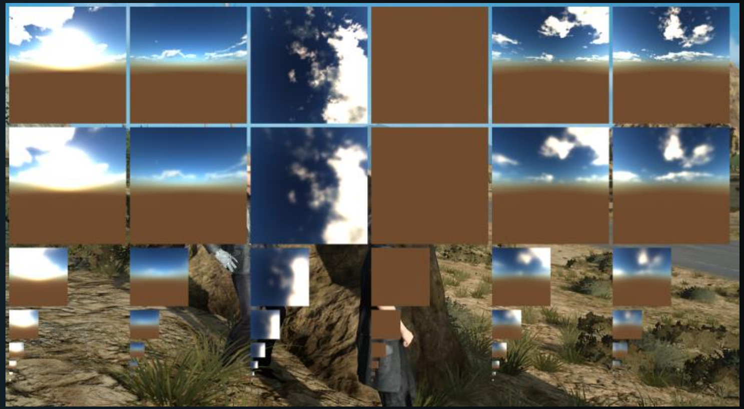
- Dynamic sky cubemap
  - Render only sky & clouds into cubemap
  - Lower hemisphere is user-defined “ground”
    - Lit by sky/sun as diffuse material



- SH Projection of Cubemap
  - For diffuse lighting by skylight.
  - Can be combined with PRT.

Sky Cubemap

- BRDF Filtering of cubemap
  - 1 face/1 mip updated per frame
  - total cycle: 48 frames (6 faces x 8 mips)



- Frame rate stability
  - Smaller mip levels require more filter kernel samples
  - Hence the filtering cost per frame stays roughly constant.
- Problem: fast change of sky (e.g. around sunset)
  - Sky cubemap's intensity is divided by total sky luminance.

Exposure

- Problem
  - Wide range of luminance
    - Sun luminance = Moon luminance * 400,000
    - We use real sky values by default.
  - Floating point precision issue.
  - Brightest pixels can be clamped.

- Solution
  - Exposure value is multiplied to all light sources, sky, etc.
  - Not apply to screen at the post-processing stage.

Results

Results

Results

12:00

Results

Results

Calibration by artists

- Photo shooting
  - Actual cubemap reference
  - 24-hours straight in HDRI

- Lighting for game
  - Calibrated each parameter based on the photo data

IBL Procedural sky

Agenda

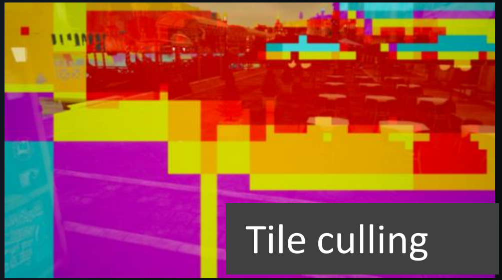
- Basic Rendering
- Global Illumination
- Sky
- Weather
  - Volumetrics
  - Rain
  - Wind
  - Weather System

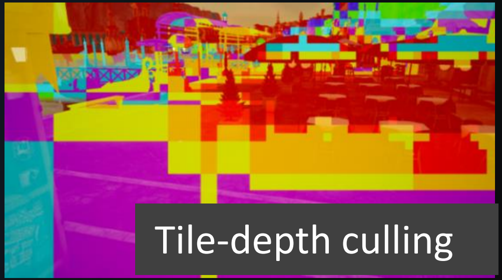
Volumetrics (fog, light shafts)

- 3d grid (160x90x64)
  - System like [Wronski, 2014]
  - Range: normally ~100m
    - Use different system for distant fog
- Lighting (optional per light)
  - Directional light
  - Local lights
  - Light probes
- Sample blurred shadow that makes light shafts
- Noise, wind animation, etc.

Local Lights

- Tile/Depth culling
  - 32 depth slices, logarithmical
  - Low-res depth min/max texture
  - Each tile has a light list, and each cell has min/max of light list.
  - Light probes use tile culling.
- Local shadow map
  - Dynamic resizing of local shadow map.
  - Texture atlas

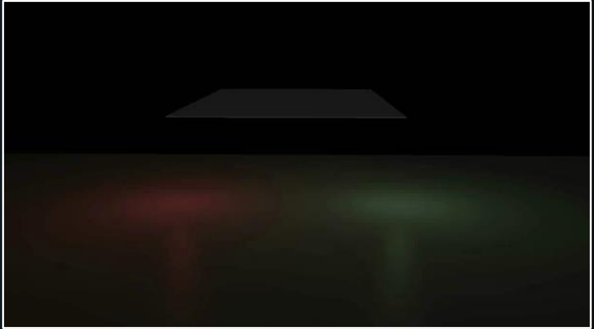




Color shows the number of lights in tile

Rain

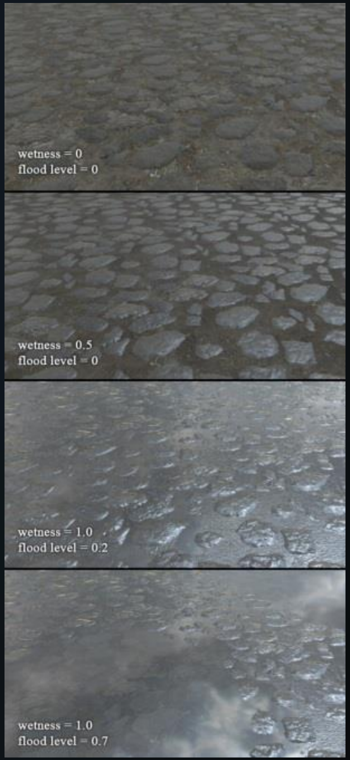
- Rain drops
  - GPU particle system
  - Falling particles centered on camera
  - Depth map collision
    - Render depth map from top view
  - Splash particles emitted from the surface



- Character Interaction

Wet Materials

- Wet shader permutation
  - Almost everything can get wet.
  - Wetness [Lagarde 2012]
    - Increases specular
    - Decreases roughness
    - Darkens diffuse
    - Distortion of normal



Wet Materials

- With in-house shaders, we made:
  - Puddles
  - Ripples
  - Trickling water
  - etc.

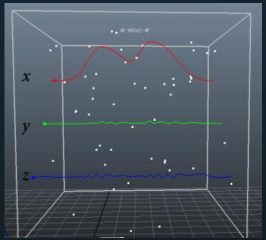
Rain: Problems

- Camera sometimes moves too fast.
  - e.g. Player character (Noctis) can warp
  - Solution: We shift particle positions during simulation when that happens.

- Wetness to dynamic objects
  - Characters/vehicles can get dry instantly when moving under a roof.
    - Because we use depth map from top view.
  - Solution: designers can place “Non wet” box.
    - Wetness decreases smoothly when they moved into a box.

Wind

- Wind system
  - Affects bone-based simulation
    - e.g. cloth, hair, fur
  - Affects vertex-based procedural motion
    - e.g. vegetation, fur
  - Wave functions can be “drawn” by designers



Weather System

- Links “weather” (set of parameters) with game entities
  - Parameters: sky, rain, wind, etc.
    - Affect shading, vfx, animation, etc.
  - Entity: area box, sequence node
- Animates parameters and changes weather.

TIME_OF_DAY	0	1	2	3	4	5	6	7	8	9	10	11	12	1
VOLLIGHT_FARFOG_THICKNESS	2000			2000	0.5								0.5	
VOLLIGHT_FARFOG_ZNEAR	200													
VOLLIGHT_FARFOG_ZFAR	8000													
VOLLIGHT_FARFOG_HEIGHT_DECAY	0.3													
VOLLIGHT_FARFOG_DISTANCE_DECAY	0.02													
VOLLIGHT_FARFOG_DEPTH_DECAY	0.3													
VOLLIGHT_FARFOG_EXTINCTION	0.001				0.001			5					5	
VOLLIGHT_FARFOG_TINT_R	0.5				0.5	0.23							0.23	
VOLLIGHT_FARFOG_TINT_G	0.5				0.5	0.5							0.5	
VOLLIGHT_FARFOG_TINT_B	0.5				0.5	0.82							0.82	
VOLLIGHT_FARFOG_STANDARD_HEIGHT	0													
VOLLIGHT_FARFOG_BOTTOM_HEIGHT	-100													
VOLLIGHT_FARFOG_PLAYER_RELATIVE	0													
RAIN_PARTICLE_EMIT_RATE	0													
RAIN_DEPTH_MAP_RADIUS	100													
RAIN_EMIT_RADIUS	30													
RAIN_EMIT_HEIGHT	50													
RAIN_EMIT_SPEED	40													
RAIN_EMIT_SPEEDRANDOM	10													
RAIN_EMIT_SPREAD	0.003													
RAIN_LIFE_SPAN	3													

a weather file

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Thank You

Questions ?

Extra slides for Q&A

Specular Reflection

Another solution: lerp between indoor/outdoor case

$$\boxed{(S_n D_r + L}\,)(1 - M) + K_r M$$

$$S_n D_r + L \approx (S_n + L) * \frac{lum(S_n) * D_r + lum(L).\mathrm{xxx}}{lum(S_n + L)}$$

$$= keycolor \; * (ratio \; * D_r + 1 \; - ratio)$$

where $keycolor = S_n + L$

$ratio = lum(S_n) \, / \, lum(S_n + L)$

Rendering pipeline

- Use of Async pipes