unity

DirectX Ray Tracing in Unity 2019.3

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Generative Art — Made with Unity

DXR Integration and Overview

DXR Overview

API designed to leverage hardware-accelerated ray tracing

Why trace rays?

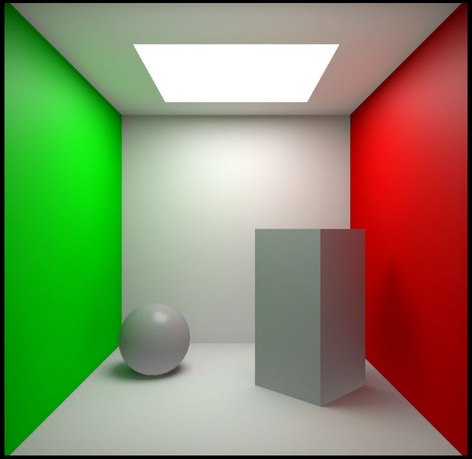
- Off-screen rendering (reflection, refraction)
- Algorithms that call for raycasting

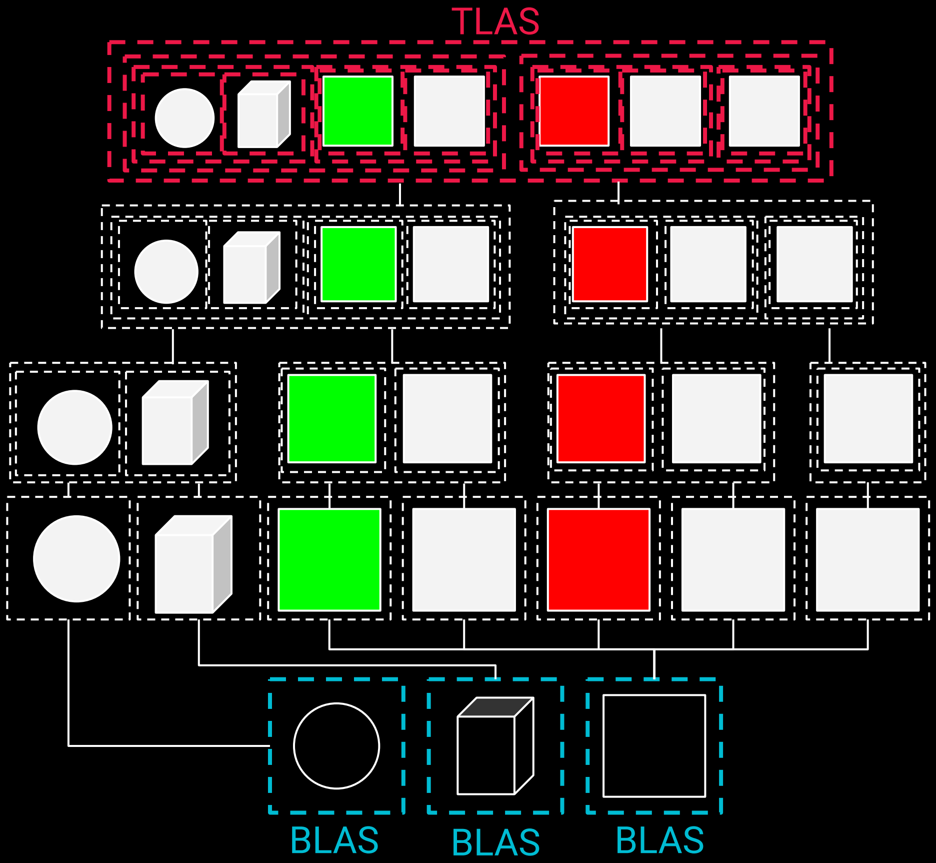
Two major concepts to be concerned with:

- Ray Tracing Acceleration Structures:
  What are we drawing?
- Ray Tracing Shaders:
  How should we draw things?

Acceleration Structure

- Bottom-Level AS: Geometry only
- BVH construction done by driver
- Top-Level AS: Geometry, materials, transforms, hierarchy





Acceleration Structure

New Unity class: **RayTracingAccelerationStructure**

- May be manually or automatically managed
  - Manual: AddInstance(), UpdateInstanceTransform()
- Specify layer masks on creation to filter which GameObjects may be added
- Call BuildRayTracingAccelerationStructure once a frame

Acceleration Structure Management

New Renderer setting: **RayTracingMode**

In order from least to most expensive:

1. Off
2. Static
3. DynamicTransform
4. DynamicGeometry

Ray Tracing Shaders

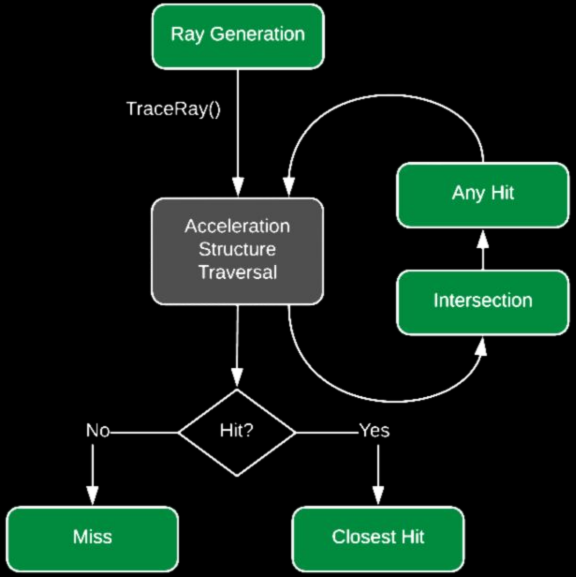
Raytrace Shaders

- RayGen: First shader executed on dispatch
- Miss: Executes if ray fails to intersect with any geometry that has a hit shader

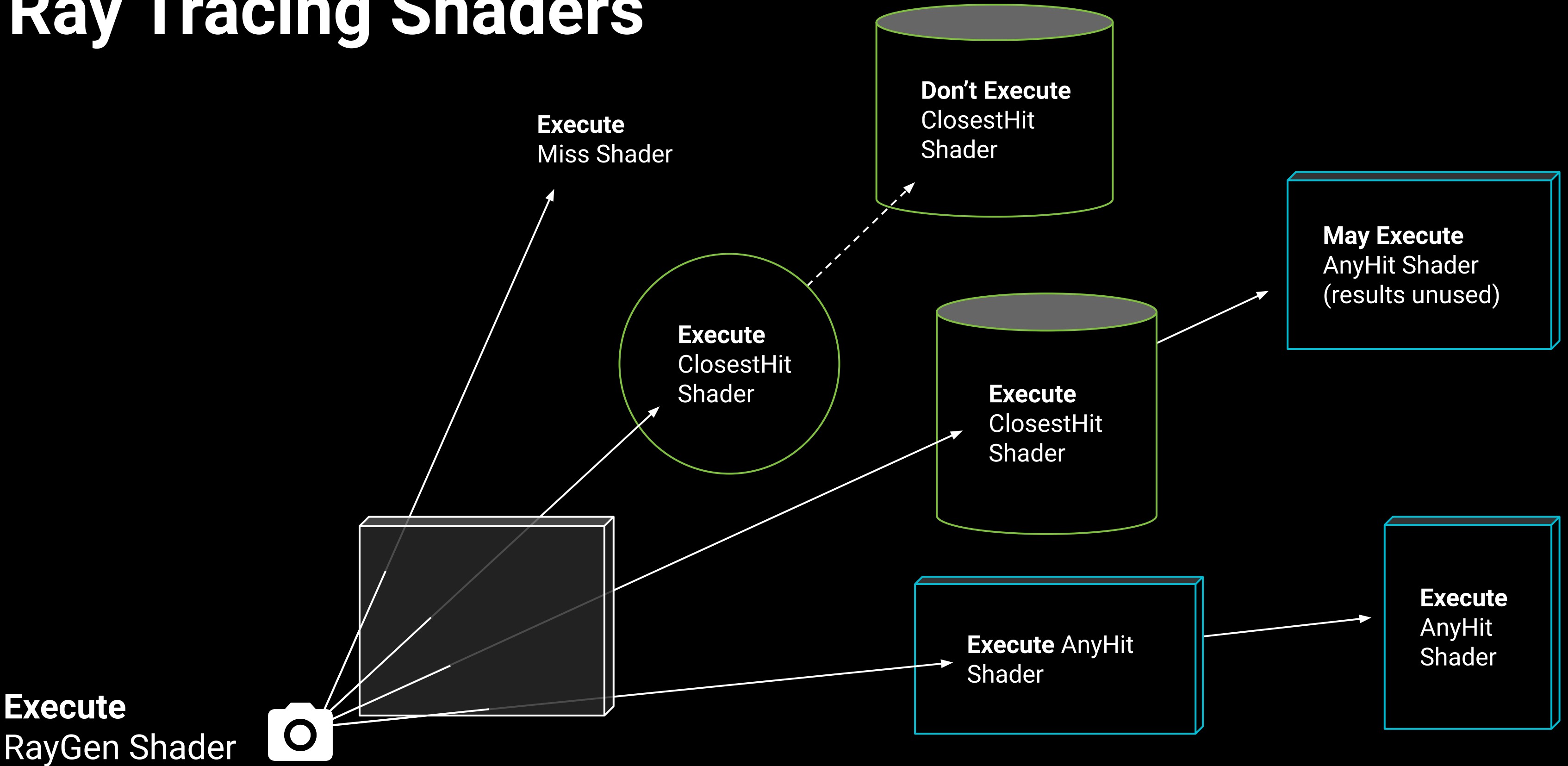
Surface Shaders

- ClosestHit: Executes on hit nearest to ray origin
- AnyHit*: Executes on every intersection

Callable Shaders



Ray Tracing Shaders



Execute Miss Shader

Don't Execute ClosestHit Shader

May Execute AnyHit Shader (results unused)

Execute ClosestHit Shader

Execute ClosestHit Shader

Execute AnyHit Shader

Execute AnyHit Shader

Execute RayGen Shader

Ray Tracing Shader API

- New shader type: RayTracingShader
    - Extension is .raytrace
- New CommandBuffer API:
    - CommandBuffer.SetRayTracingShaderPass
    - CommandBuffer.SetRayTracingAccelerationStructure
    - CommandBuffer.SetRayTracing*Param
        - e.g. SetRayTracingMatrixParam, SetRayTracingIntParam, etc.
    - CommandBuffer.DispatchRays
    - Analogous bindings also available from RayTracingShader class itself, for immediate execution

Ray Tracing Shader Authoring

```
// Dispatch shader: Defines at minimum a ray generation shader, often also a miss shader.
// This is the shader that is dispatched, as one would a compute shader,
// for a given ray traced pass.

struct RayPayload { float4 color; uint2 launchIdx; }; // User-defined

[shader(“raygeneration”)]
void FullResRayGen()
{
    uint2 launchIdx = DispatchRaysIndex().xy; // DXR callback
    uint2 launchDim = DispatchRaysDimensions().xy; // DXR callback
    float2 ndcCoords = (launchIdx / float2(launchDim.x - 1, launchDim.y - 1)) * 2 - float2(1, 1);
    float3 viewDirection = normalize(float3(ndcCoords.x * aspectRatio, ndcCoords.y, -1);
    RayDesc ray; // DXR defined
    ray.Origin = float3(camera_IV[0][3], camera_IV[1][3], camera_IV[2][3]);
    ray.Direction = normalize(mul(camera_IV, viewDirection));
    ray.TMin = 0;
    ray.TMax = 1e20f;
    RayPayLoad payload;
    payload.color = float4(0, 0, 0, 0);
    TraceRay(accelerationStructure, 0, 0xFF, 0, 1, 0, ray, payload); // DXR callback
}
```

Ray Tracing Shader Authoring

```
[shader(“miss”)]
void SampleSkybox(inout RayPayload payload : SV_RayPayload)
{
    rayDirection = WorldRayDirection();
    float4 skyboxColor = skyboxTex.SampleLevel(linearRepeatSampler, rayDirection, 0);
    payload.color = skyboxColor;
}

// These slides have a good introduction to built-in DXR callbacks:
// http://intro-to-dxr.cwyman.org/presentations/IntroDXR_RaytracingShaders.pdf
```

Surface Shader Authoring for Ray Tracing

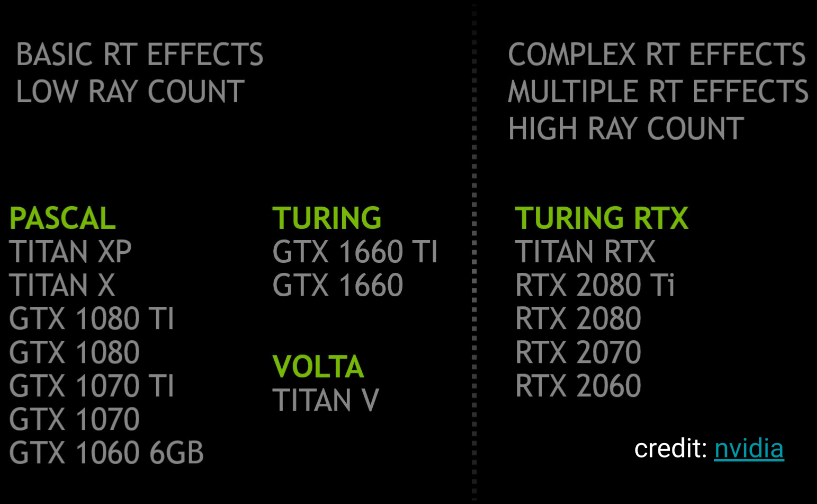
```
// Material/Surface shader: Hit shaders should be defined as a pass in a shader used for a
// material in the scene.
Shader “FlatColor”
{
        SubShader { Pass { CGPROGRAM
                #pragma vertex vert
                #pragma fragment frag
                v2f vert (appdata v) { return UnityObjectToClipPos(v.vertex); }
                fixed4 frag (v2f i) : SV_Target { return albedo; }
                ENDCG
        } }

        SubShader { Pass Name "DefaultRTPass" { HLSLPROGRAM // Pass name must match that specified by SetShaderPass()
                #pragma raytracing
                struct AttributeData { float2 barycentrics; }; // User-defined
                [shader(“closesthit”)]
                void FullResRayGen(inout RayPayload payload : SV_RayPayload,
                                   AttributeData attribs : SV_IntersectionAttributes)
                { // A trivial hit shader that populates a bound RT with albedo of hit object
                    payload.color = albedo;
                    outputRT[payload.launchIdx] = albedo;
                } ENDHLSL
        } }
}

```

Setup Requirements for DXR in Unity

- Windows 10 v1809+
- Unity 2019.3b1+
- Graphics card with latest drivers:



BASIC RT EFFECTS
LOW RAY COUNT

PASCAL
TITAN XP
TITAN X
GTX 1080 TI
GTX 1080
GTX 1070 TI
GTX 1070
GTX 1060 6GB

TURING
GTX 1660 TI
GTX 1660

VOLTA
TITAN V

COMPLEX RT EFFECTS
MULTIPLE RT EFFECTS
HIGH RAY COUNT

TURING RTX
TITAN RTX
RTX 2080 Ti
RTX 2080
RTX 2070
RTX 2060

credit: nvidia

Unity Project settings:

- Select DX12 as Windows Graphics API

Ray Tracing Setup for HDRP

- Everything on the previous slide
- Clone HDRP from Github
- Windows > Render Pipeline > HDRP Wizard > check everything under DXR additional configuration, which takes care of the following:
  - Sets DX12 as graphics API if you haven't already
  - In Project Settings > Player > Scripting Define Symbols, add REALTIME_RAYTRACING_SUPPORT
  - In HDRP Asset > Rendering, enable Realtime Raytracing
- Find ShaderConfig.hlsl in your local copy of the high-definition-config package, and change #define SHADEROPTIONS_RAYTRACING to (1)
- Add a Game Object > Rendering > Ray Tracing Environment to your scene
- For ray traced shadows: enable screen space shadows in HDRP Asset

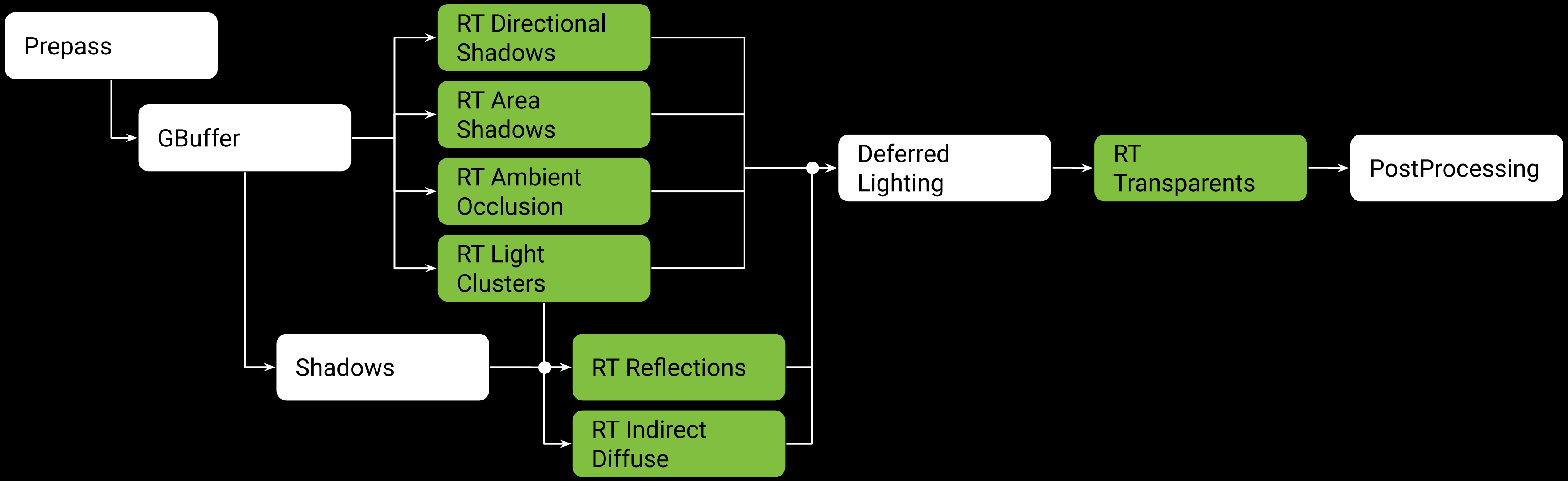
State of Unity DXR

- Ray Tracing API is pipeline-agnostic
  - However, it’s only officially supported for HDRP
    - HDRP is also the only pipeline that actually implements features using ray tracing
    - In ShaderGraph, HDRP master nodes for Lit, Unlit, and Fabric support ray tracing
  - Users can still use the public C# API to build their own features!
- Unsupported in 19.3:
  - Intersection shaders
  - Animated meshes
  - Procedural geometry

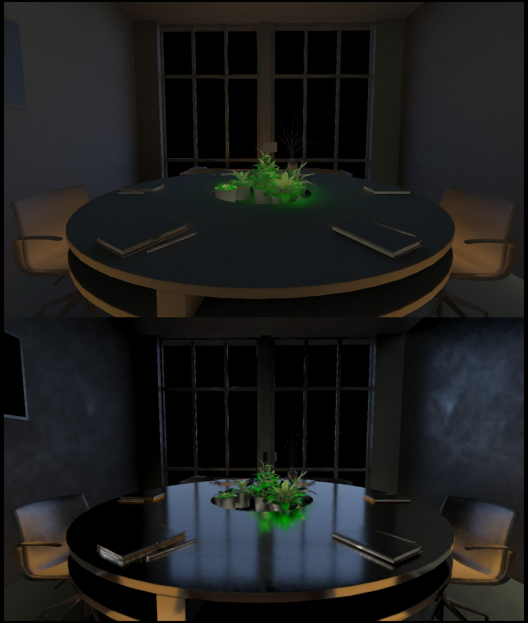
Ray Tracing Features in the High Definition Render Pipeline

Architecture

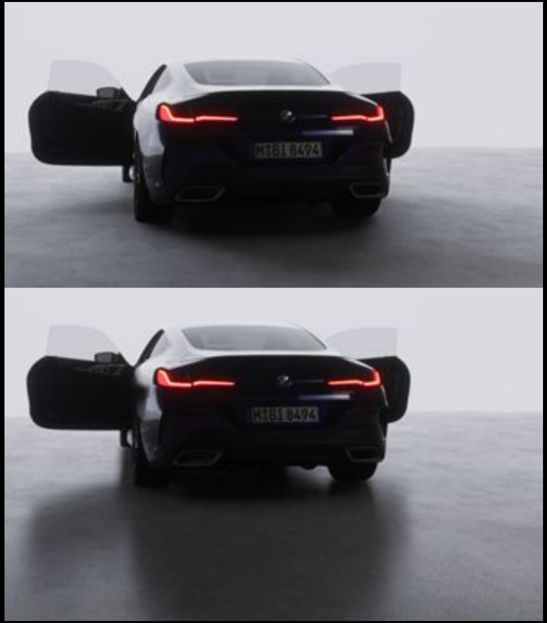
- Primary rays for most effects are computed from depth/normal buffers
- Cluster-based lighting added to HDRP for ray tracing
- Render graph here is **simplified** and **omits** many HDRP stages



Ray Traced Effects



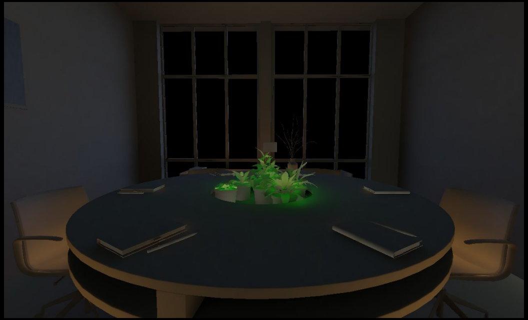
Indirect Lighting



Shadows

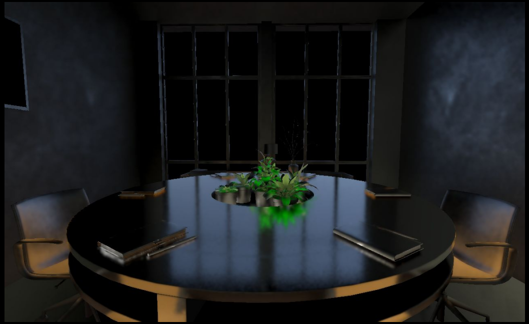
Transparents

Ray Traced Indirect Lighting



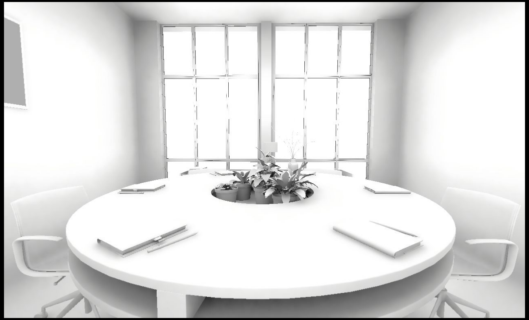
Global Illumination
(Indirect Diffuse)

- Lambert lobe sampling
- Multiple bounces
- Temporally accumulated



Reflections
(Indirect Specular)

- Isotropic GGX lobe sampling
- Split sum approximation
- Multiple bounces
- Temporally accumulated

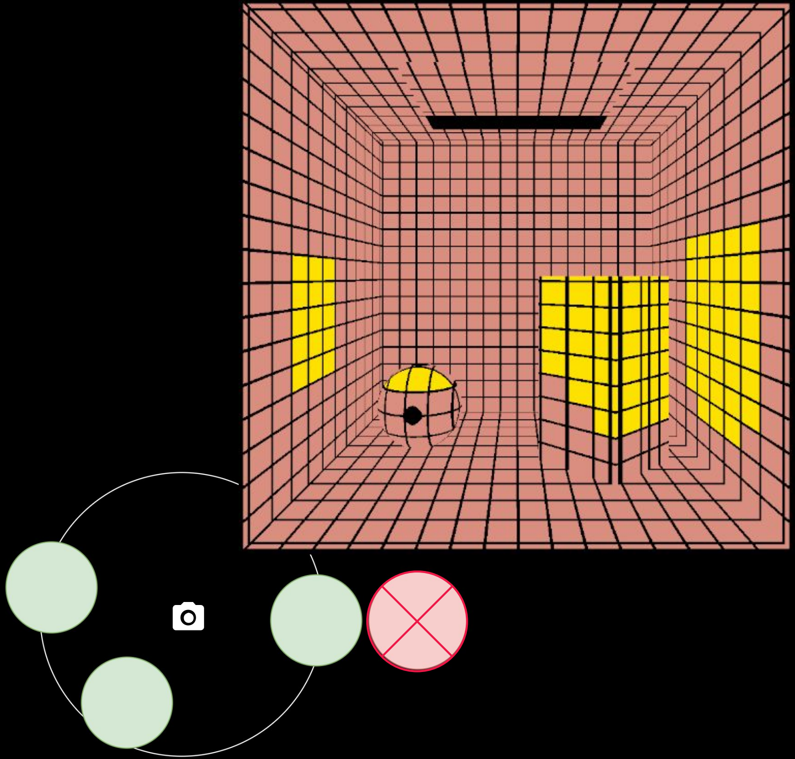


Ambient Occlusion

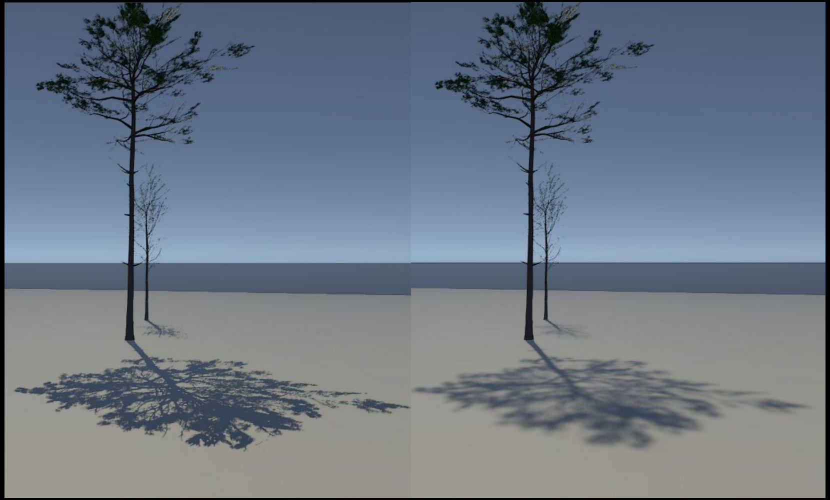
- Not technically lighting
- Same as GI but only visibility/no color
- 1 bounce

Cluster Based Light Lists

- Ray Tracing must look up light list given 3D intersection location in scene
- Populated with lights within culling radius of camera
- Debug view shows # of lights affecting a given cluster



Ray Traced Shadows



Directional Lights:

- Ray-traced screen space soft shadows
- Sun modeled as adjustable-size disk

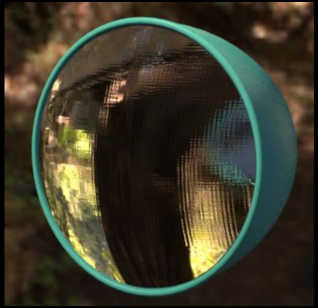
Area Lights:

- Rays cast across surface of area light
- Combined with analytic lighting using a ratio estimator

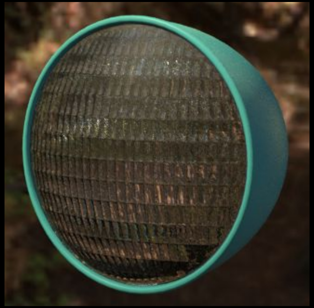
Transparents

- Need angle of incidence, so trace primary rays (rather than constructing first hit from GBuffer)
- Each bounce generates 2 rays: one for transmission, one for reflection
- More overlapping transparent layers require more bounces

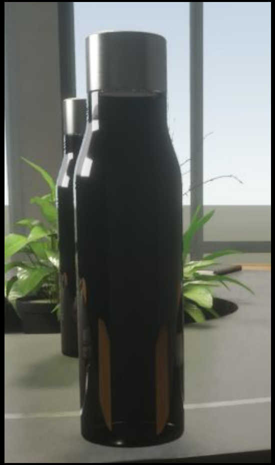
Screen space refraction



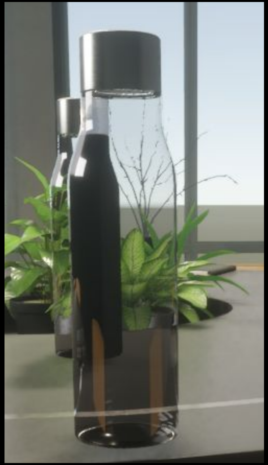
Recursive ray tracing



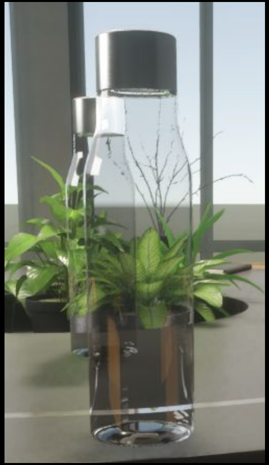
3 bounces



5 bounces



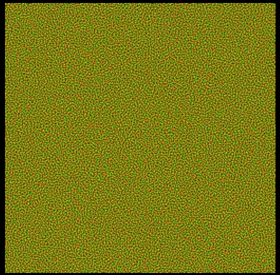
7 bounces



Spatiotemporal Sampling

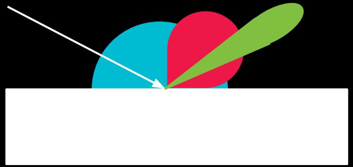
Sample count is configured per-effect.

1. **Ray pixel coordinates** are used to sample spatial noise from dithered blue-noise texture
2. Spatial noise results and **frame index used** to sample temporal noise from a looping Sobol sequence
3. Resulting value is mapped to the appropriate PDF for each effect to calculate **raycast direction**



Blue Noise Tile 256x256x2

Owen Scrambled Sobol Sequence 256x1x4

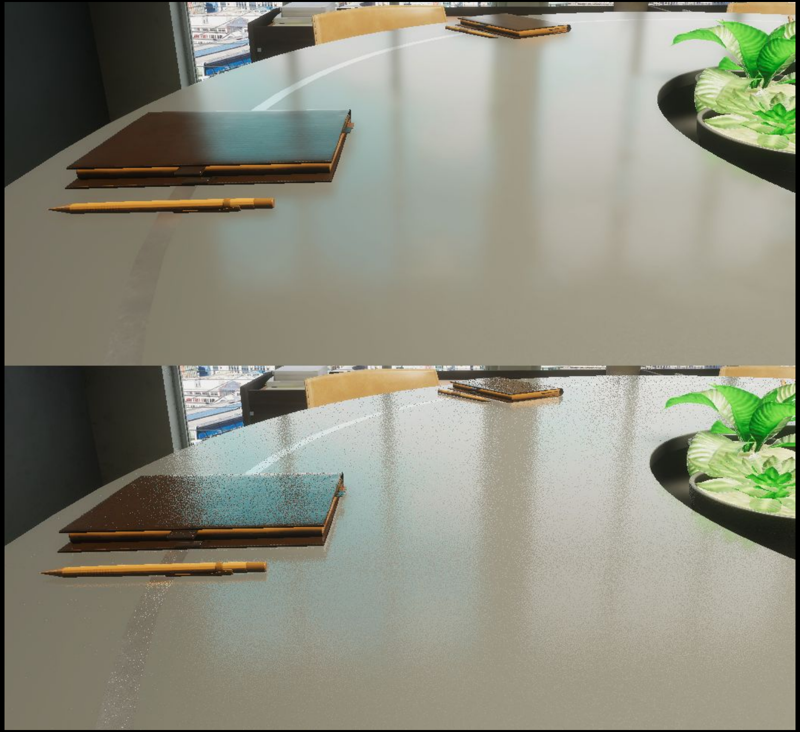


Example lobes for secondary ray directions

Denoising

Denoising is done per-effect in a compute shader:

- Temporal sample accumulation
  - Use accumulated samples across previous 8 frames
  - Previous frames reprojected to correct for camera motion
- Separable Bilateral Gaussian filtering
  - Uses depth/normal buffers detect and avoid artifacting at edges
  - Incompatible with transparents



Optimization Knobs

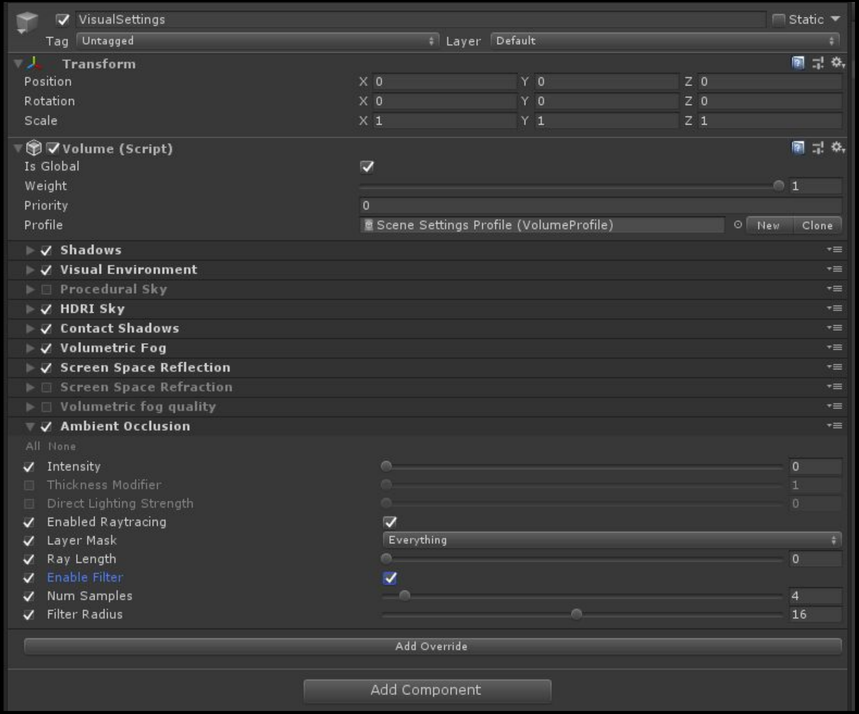
Ray tracing effects may be accessed in the volume inspector

Per-Effect config

- Ray length
- # samples
- # bounces

Content management

- Mesh count
- Per-effect and per-camera layer masks
- Selective application of effects



☑ VisualSettings □ Static

Tag Untagged Layer Default

Transform

Position X 0 Y 0 Z 0

Rotation X 0 Y 0 Z 0

Scale X 1 Y 1 Z 1

☑ Volume (Script)

Is Global ☑

Weight 1

Priority 0

Profile Scene Settings Profile (VolumeProfile) New Clone

☑ Shadows

☑ Visual Environment

□ Procedural Sky

☑ HDRI Sky

☑ Contact Shadows

☑ Volumetric Fog

☑ Screen Space Reflection

□ Screen Space Refraction

□ Volumetric fog quality

☑ Ambient Occlusion

All None

☑ Intensity 0

□ Thickness Modifier 1

□ Direct Lighting Strength 0

☑ Enabled Raytracing ☑

☑ Layer Mask Everything

☑ Ray Length 0

☑ Enable Filter ☑

☑ Num Samples 4

☑ Filter Radius 16

Add Override

Add Component

Acknowledgements

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Natasha Tatarchuk

Joel de Vahl

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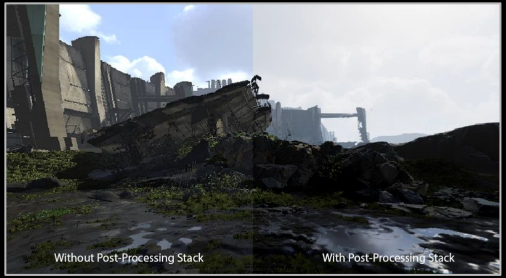
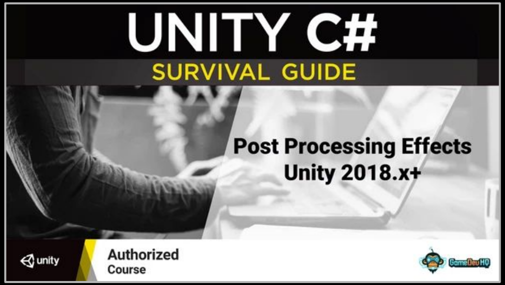


Tutorial:
Introduction to the Post Processing Stack



Tutorial:
Post-Processing Effects (2018.x+)

Tutorial:
Particle System: Lights

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Thank you.

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Generative Art — Made with Unity

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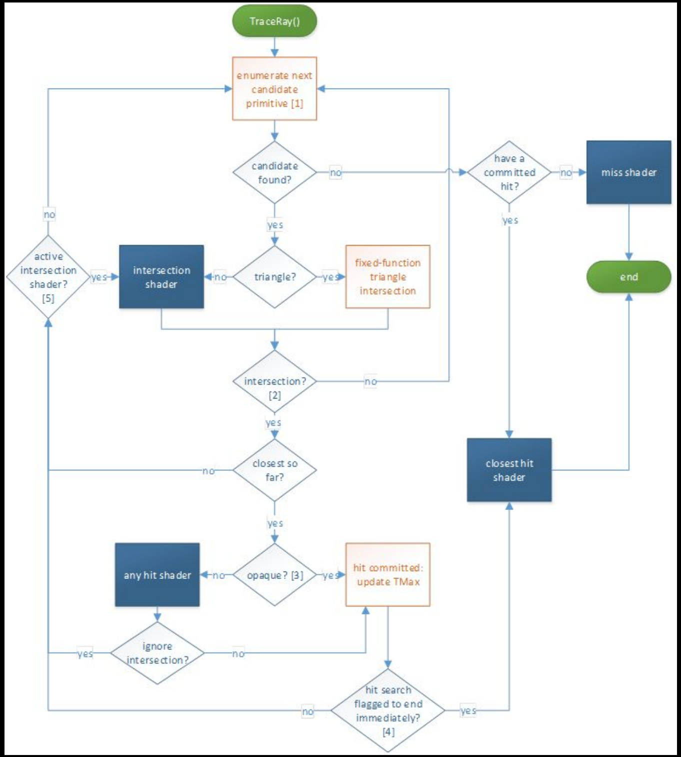
Resources

Ray Tracing Shader Execution

https://microsoft.github.io/DirectX-Specs/d3d/Raytracing.html

AnyHit:

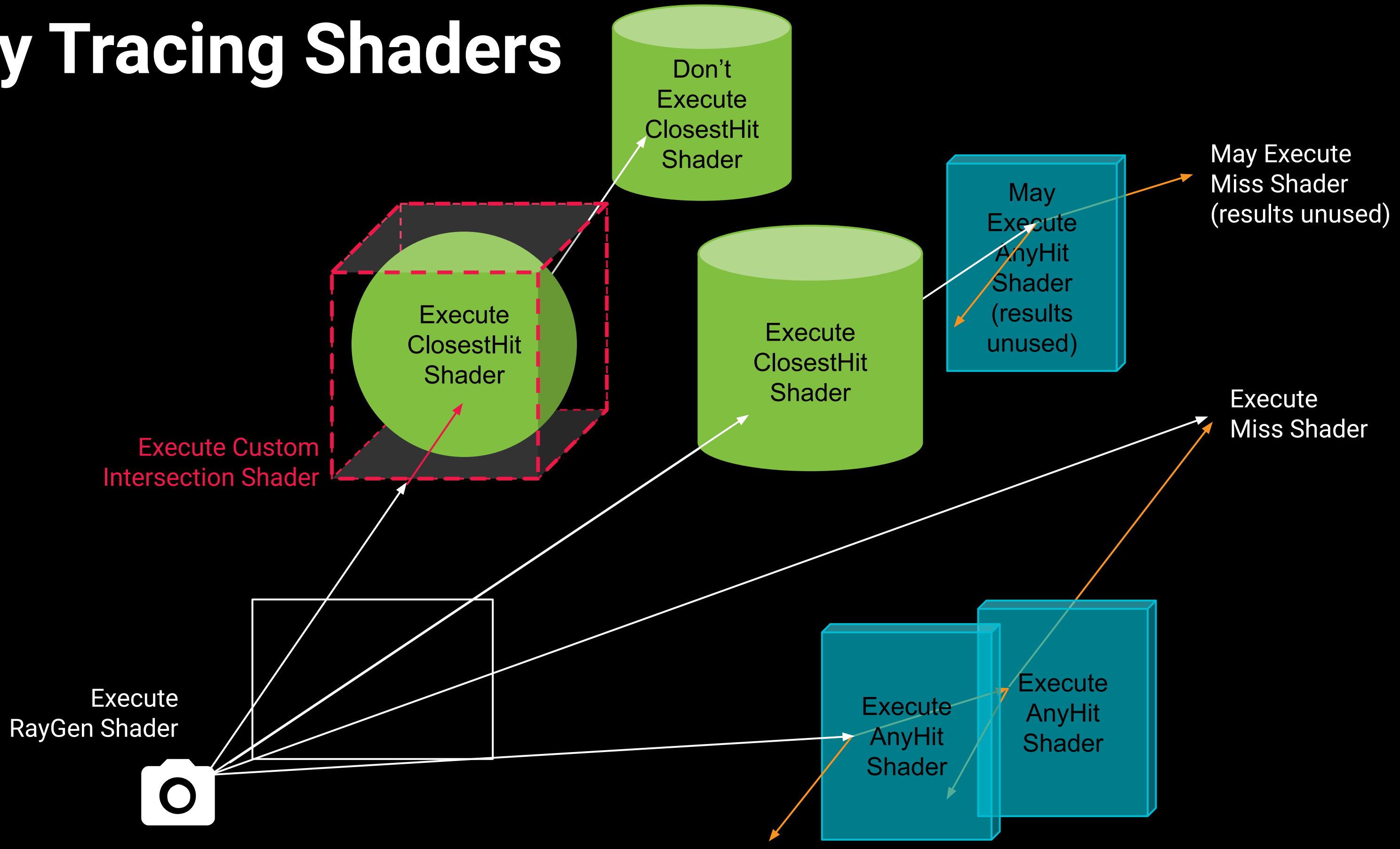
“The TMin value tracked by the system never changes over the lifetime of a ray. On the other hand, as intersections are discovered (in arbitrary spatial order), the system reduces TMax to reflect the closest intersection so far. When all intersections are complete, TMax represents the closest intersection, the relevance of which appears later...”



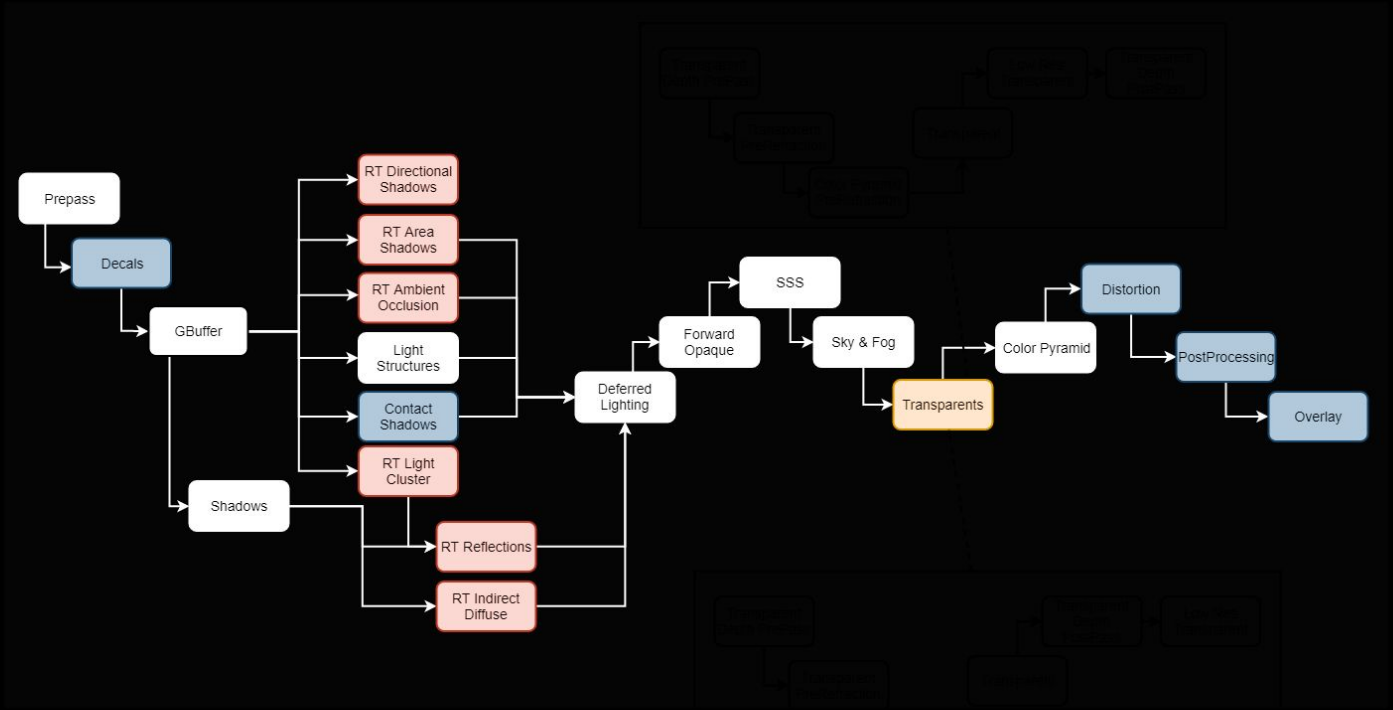
AnyHit

- IgnoreHit()
- AcceptHitAndEndSearch()
- Otherwise, implicitly accepts hit and continues traversal

Ray Tracing Shaders


Don't Execute ClosestHit Shader
Execute ClosestHit Shader
Execute Custom Intersection Shader
Execute ClosestHit Shader
May Execute AnyHit Shader (results unused)
May Execute Miss Shader (results unused)
Execute Miss Shader
Execute AnyHit Shader
Execute AnyHit Shader
Execute RayGen Shader

Hybrid Render Graph



Indirect Specular

$$L_{\text{indirect specular}} \approx \int_{\Omega} \boxed{\frac{\mathrm{F\,G}\,D}{4(\omega_{\mathrm{i}} \cdot \mathbf{n})(\mathbf{v} \cdot \mathbf{n})}}\, \boxed{L_{\text{indirect}}\,(\omega_{\mathrm{i}} \cdot \mathbf{n})}\, d\omega_{\mathrm{i}}$$

$$L_{\text{indirect specular}} \approx \boxed{specularFGD}\, \boxed{\int_{\Omega} \frac{(\mathbf{h} \cdot \mathbf{n})\, D}{4(\mathbf{h} \cdot \mathbf{n})}\, L_{\text{indirect}}\,(\omega_{\mathrm{i}} \cdot \mathbf{n})}\, d\omega_{\mathrm{i}} \quad *$$