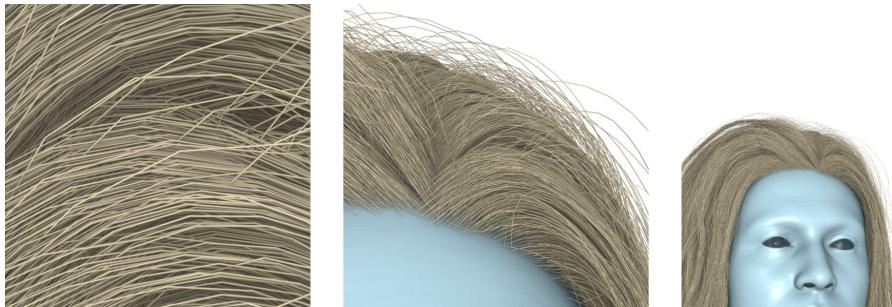


Line Swept Sphereについて

@kenhu07
レイトレ合宿11

NVIDIA Blackwell Line Swept Sphere (LSS)

- NVIDIA Blackwell、レイトレ BVHにLSSサポート追加された
- 髪の毛などを表現する際に従来のTriangle Meshに比べて効率化

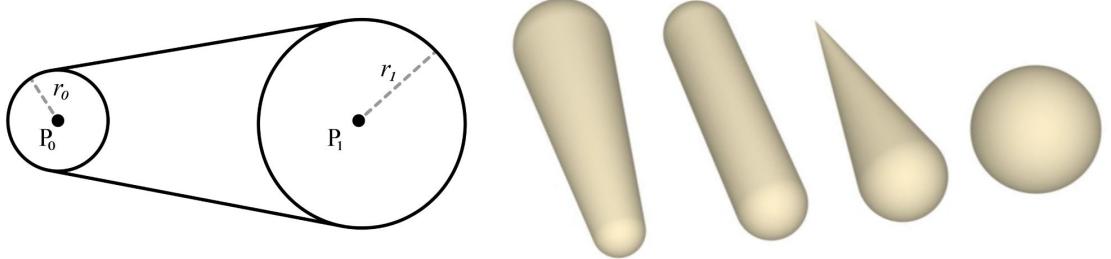


<https://developer.nvidia.com/blog/render-path-traced-hair-in-real-time-with-nvidia-geforce-rtx-50-series-gpus/>

1. Line Swept Sphereとは
2. NVIDIA API
3. 応用例？
4. 関連資料

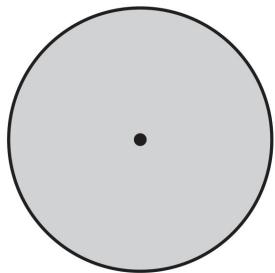
Line Swept Sphere (LSS)

- 名前通りにLineに沿ってSphereを伸ばしたと思ったら、Radiusが変化する！
- なぜか “Line Swept Sphere” でGoogleするとNVIDIAの話が上位に出る？
- 一般的な用語に見えるが？

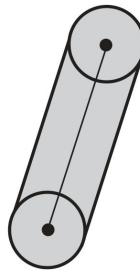


Swept-Sphere Volumes (SSV) / Sphere-Swept Volumes

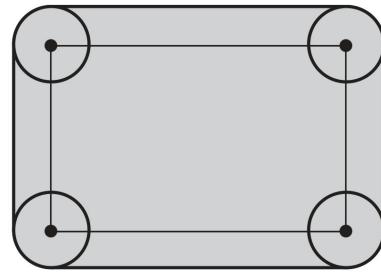
- Collision Detection 文脈の用語ではある、表記の揺らぎがあるみたい
- ただし Radius が変化しないことが多い



Sphere-Swept Point (SSP)
Point Swept Sphere (PSS)
Sphere



Sphere-Swept Line (SSL)
Line Swept Sphere (LSS)
Capsule
Capped Cylinders
Spherocylinders

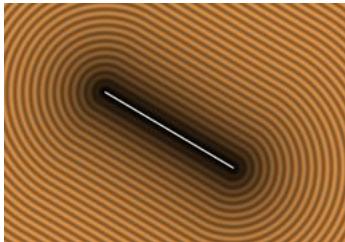


Sphere-Swept rectangle (SSR)
Rectangle Swept Sphere (RSS)
Lozenge (?)

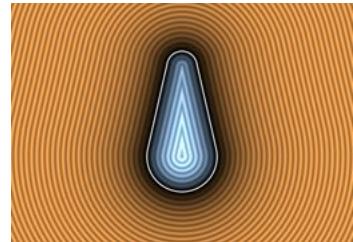
5

- Real-Time Collision Detection
 - 4.5 Sphere-swept Volumes
 - [Larsen99] Fast Proximity Queries with Swept Sphere Volumes
 - [Larsen00] Fast Distance Queries Using Rectangular Swept Sphere Volumes
 - [Xavier97] Fast Swept-volume Distance for Robust Collision Detection
- Geometric Tools
 - <https://www.geometrictools.com/Documentation/IntersectionMovingSphereTriangle.pdf>

Signed Distance Field (shadertoy)



Segment



Uneven Capsule



Capsule / Line

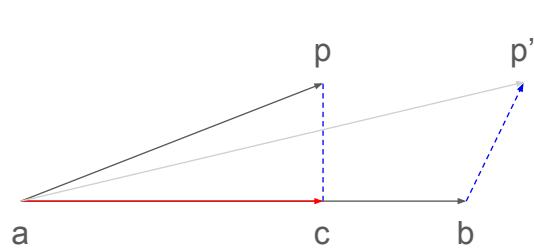
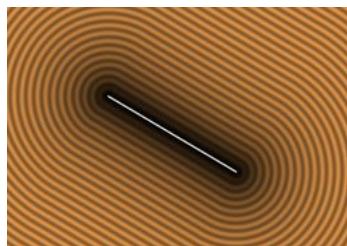


Round Cone

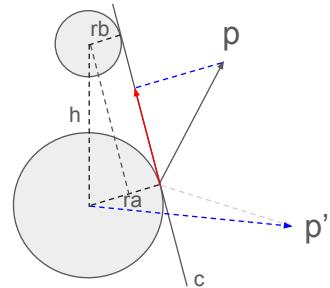
6

- 2D distance functions <https://iquilezles.org/articles/distfunctions2d/>
- 3D distance functions <https://iquilezles.org/articles/distfunctions/>

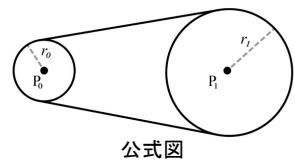
Signed Distance Field (shadertoy)



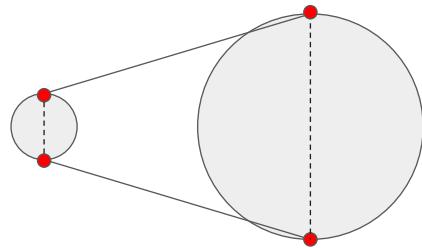
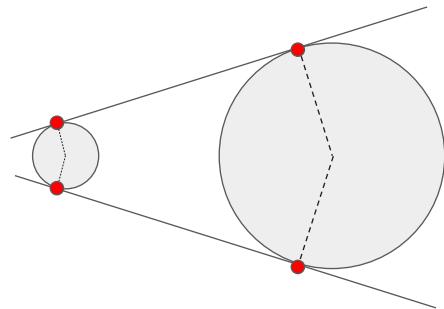
pをabに投影cがa,bの間にclamp、距離 = $|pc - pc'|$



Line Swept Sphere? Line Swept Circle?



公式図



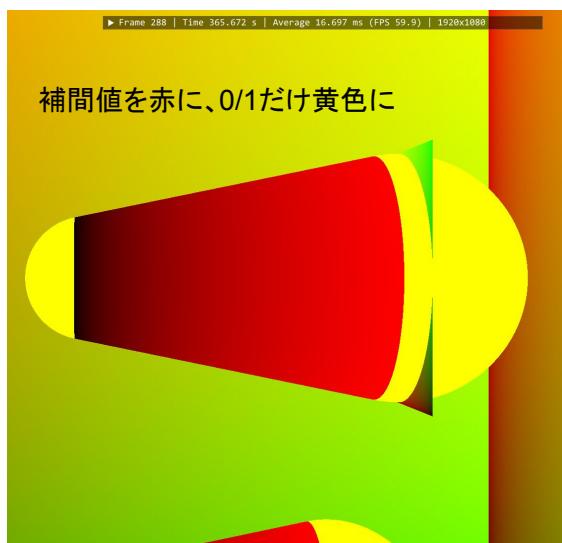
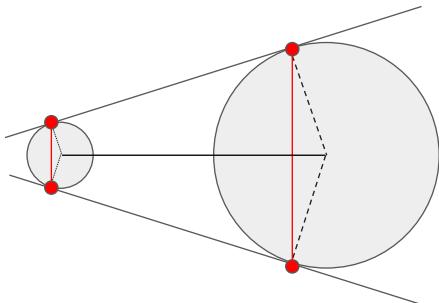
NVIDIA API を使って試してみた



NVIDIA API を使って試してみた



NVIDIA API を使って試してみた



NVIDIA API を使って試してみた

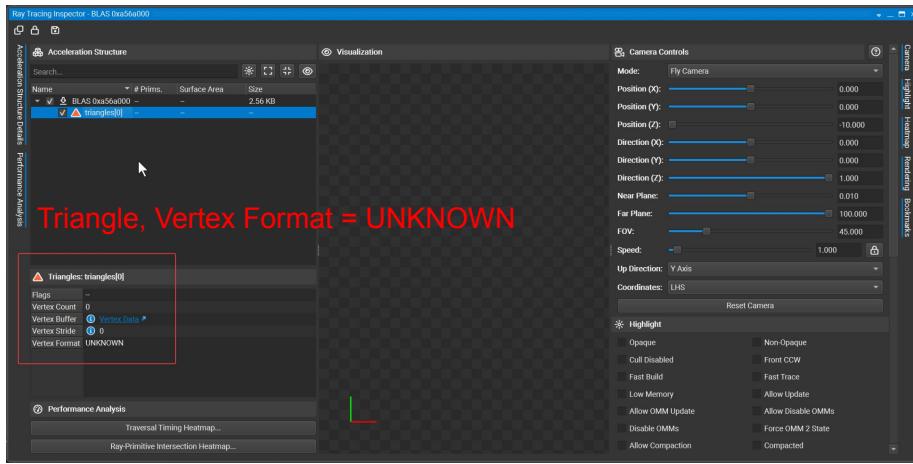
確かに Line Swept Sphere !

NVIDIA API

- GPU
 - Blackwell (50x0)
- Graphics API
 - DirectX: NVAPI_D3D12_RAYTRACING_CAPS_TYPE_LINEAR_SWEPT_SPHERES
 - Vulkan: VK_NV_ray_tracing_linear_swept_spheres
 - OptiX: サポートしているらしいが、どれがに相当するか見当たらない
 - OPTIX_PRIMITIVE_TYPE_ROUND_LINEAR ? **circular cross-section** だけど？
- BLAS 構築
 - **Position / Index / Radius** (Stride 0で固定値指定)
 - Format: List (頂点ごと) / Successive Implicit(線分ごと)
 - メモリ節約が売りのはずだけど、髪の毛想定ならもっとコンパクトできないか ... ?

NVIDIA Nsight 2025.4.1.0

対応されていない？！

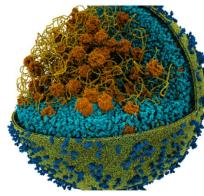
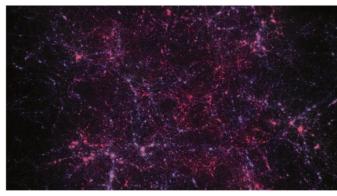
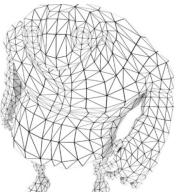


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せっかくHWサポートなので、パフォーマンス見てみたかった

事例

- RTX Hair in Indiana Jones and the Great Circle
 - 現時点唯一のプロダクションレベルの応用例とも言える ...
- RTX Character Rendering (RTXCR)
 - NVIDIAから提供しているSDK、サンプル付き
- Hair以外への応用
 - “**Particles, molecular models, wireframe rendering, font and path rendering, and whatever else you can imagine**” – NVIDIA公式ページ
 - NVIDIA APIを動かしたのでついでに軽く試した



RTX Hair in Indiana Jones and the Great Circle

ライティングへの影響が大きい、ただ資料公開されていない..



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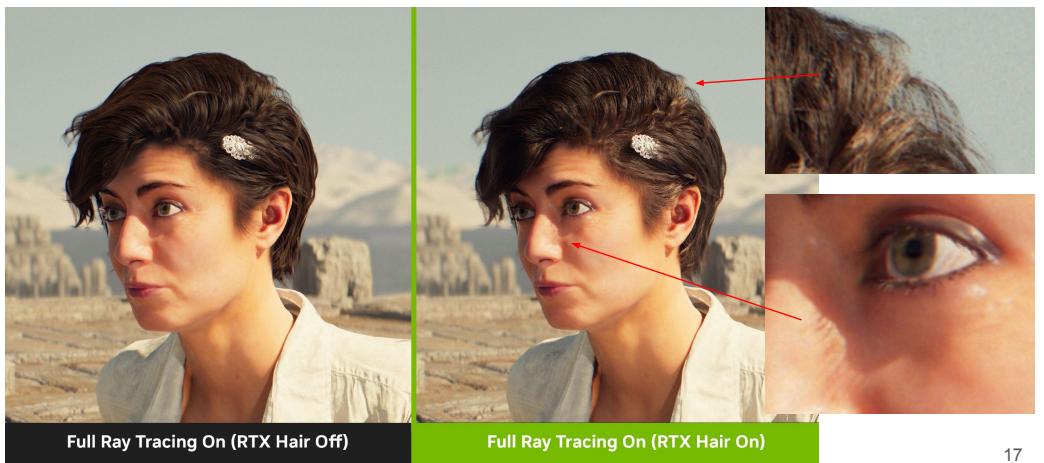
https://x.com/GeForce_JacobF/status/1878342360943210785

<https://www.guru3d.com/story/nvidia-rtx-hair-debuts-in-indiana-jones-and-the-great-circle/>

<https://www.youtube.com/watch?v=Qdwcllp-pb8>

RTX Hair in Indiana Jones and the Great Circle

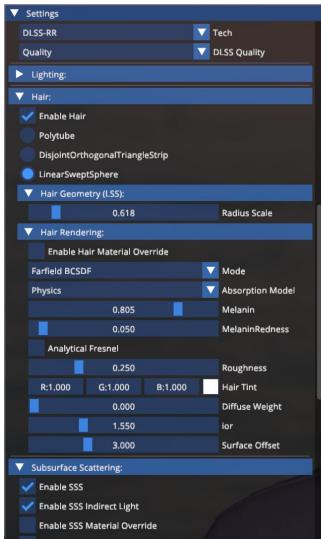
おそらく近似処理を省いたおかげでより繊細に見える



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クオリティ落ちてるところあるけど?
まつげの影はなんかいい

RTX Character Rendering (RTXCR)



頂点数

ClaireHair_Polytail: 1,151,172

ClaireHair_Main: 1,873,166

ClaireHair_BabyHairFront: 228,424

ClaireHair_BabyHairBack: 59,248

合計: 3,312,010

Index使わない構成のようで

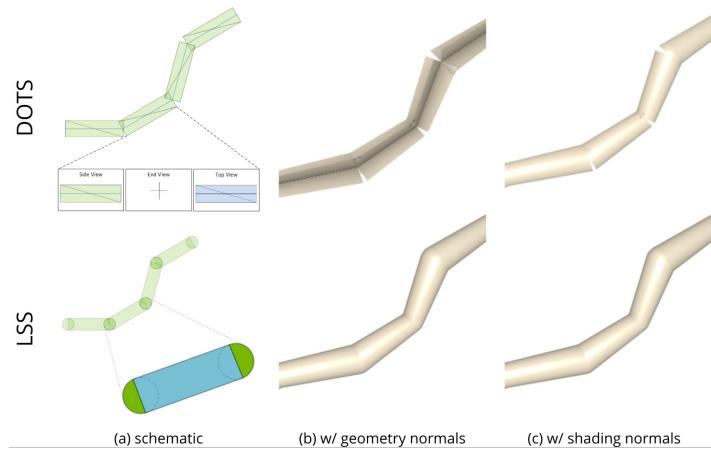
$3,312,010 / 2 = 1,656,005$ LSS

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数での勝負 ...

RTX Character Rendering (RTXCR)

従来手法: Disjoint Orthogonal Triangle Strips (DOTS)、つまり板2枚十字に配置



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どこで使われてるのか？

RTX Character Rendering (RTXCR)

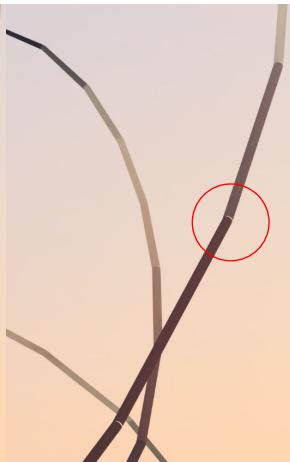
Polytube



DOTS



LSS



EndCaps有効だと↑

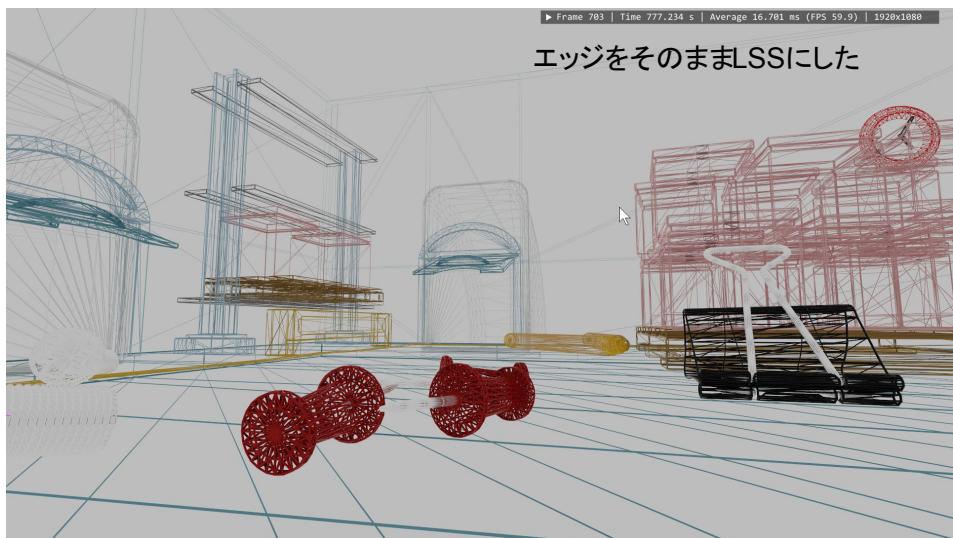


本来両端以外自動に繋ぐはずだが
作成時Index使ってなく
実質接続情報がないかも

20

なんか途切れてない！？

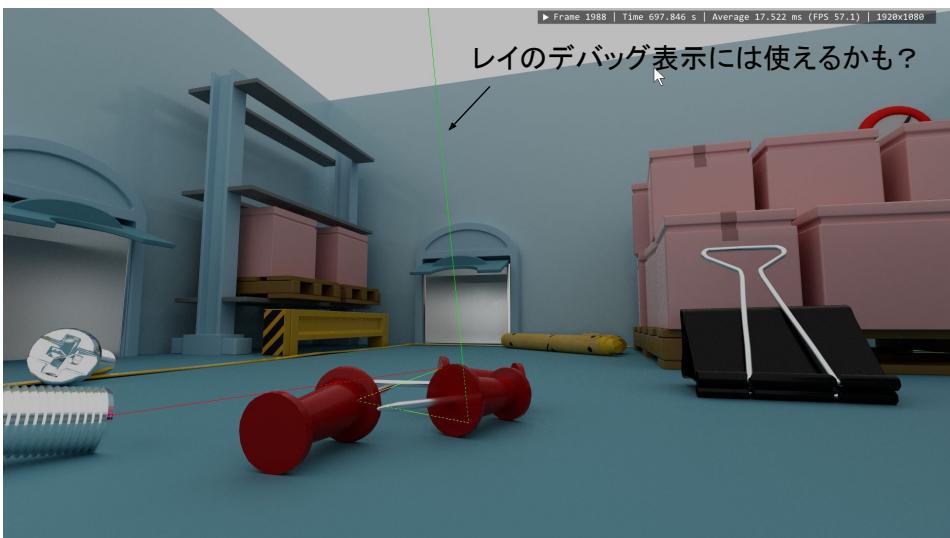
Wireframe実験



21

自分のRendererにRasterization Pass対応していないので、wireframeできなかった。一度 barycentric を見て anyhit させるのが試した。レイトレにおいて正攻法あるのか ... ?

Wireframe実験

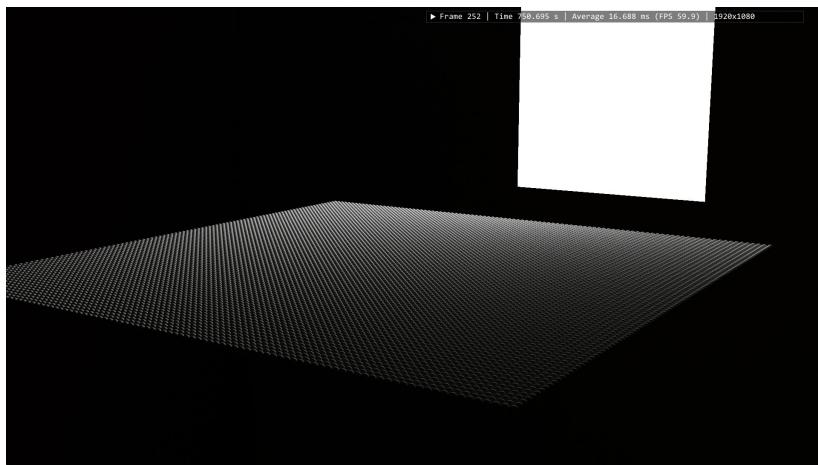


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いまは LINE_LIST で書いてるが、ちょっと細い

BRDF実験 (?)

100 x 100 Sphere

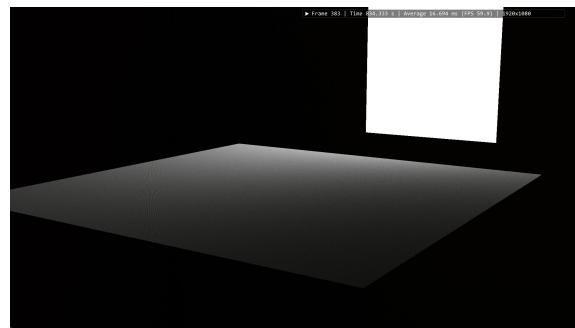


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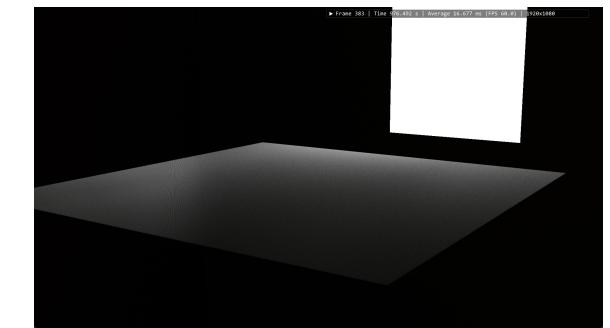
LSSの長さを 0 にすれば Sphere になるが、API的に Sphere はまた専用 Primitive として分けられている

BRDF実験 (?)

Scale なし



1000 x 1000 Sphere



縦方向 10x Scale

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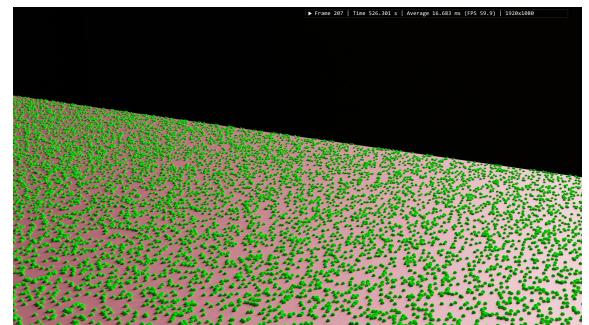
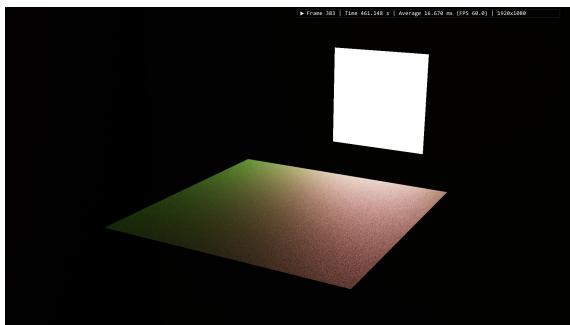
雰囲気的な rough diffuse、検証はしていない
GGX は確実に検証できそう

BRDF実験 (?)



A Micrograin BSDF Model for the Rendering of Porous Layers

Conductor板にDiffuse球



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<https://dl.acm.org/doi/10.1145/3610548.3618241>

前のと同じく、出してみただけで、検証はしていない

Hair 関連資料

- Hair Strand x Rasterization(ゲーム)
 - EA Frostbite: **Every Strand Counts: Physics and Rendering Behind Frostbite's Hair**
 - ほかCapcom RE、Unrealなども、
- Hair Strand x Ray Tracing
 - Piecewise Linear Curve + Round end caps (OptiX)
 - Blackwell LSSがこれに相当
 - Phantom (OptiX) ~ Swept Circle
 - 2018 - Alexander Reshetov, David Luebke - Phantom Ray-Hair Intersector
 - Rocaps (OptiX) ~ Swept Sphere
 - 2024 - Alexander Reshetov, David Hart - Modeling Hair Strands with Roving Capsules

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<https://raytracing-docs.nvidia.com/optix9/guide/index.html#curves#rocaps-curves>

https://raytracing-docs.nvidia.com/optix9/guide/optix_guide.250703.A4.pdf

> Starting with the Nvidia Blackwell architecture, spheres and linear curves are hardware accelerated

> Phantom uses a swept circle whereas Rocaps uses a swept sphere

> Practically speaking for curves used to represent hair and fur (thin low curvature geometry), the shapes of Phantom and Rocaps are interchangeable

<https://forums.developer.nvidia.com/t/optix-9-rocaps-curve-evaluator/323280>

Also

2022 - Alexander Reshetov - Ray/Ribbon Intersections

https://research.nvidia.com/index.php/publication/2022-07_rayribbon-intersections

2019 - Alexander Reshetov - Cool Patches: A Geometric Approach to Ray/Bilinear Patch Intersections

https://research.nvidia.com/publication/2019-03_cool-patches-geometric-approach-ray-bilinear-patch-intersections

/// Piecewise linear curve with circular cross-section.

OPTIX_PRIMITIVE_TYPE_ROUND_LINEAR

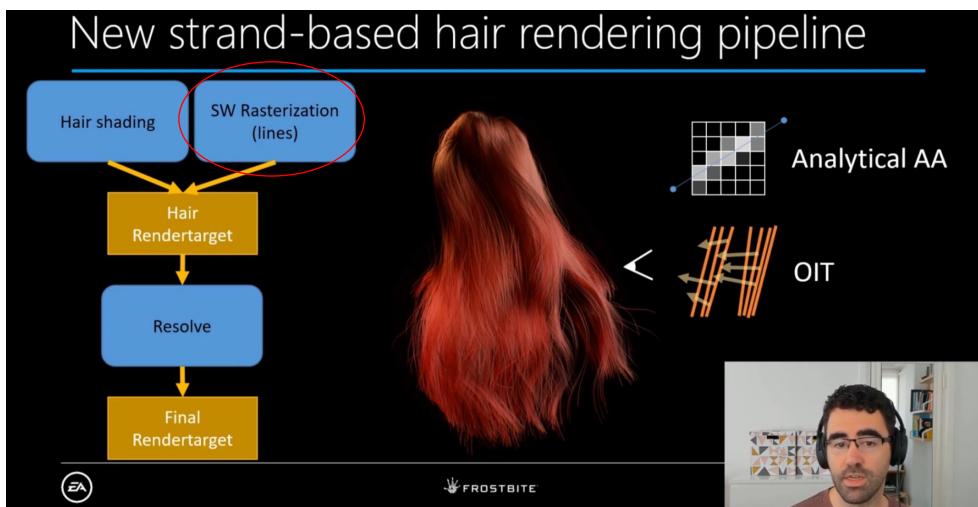
/// Default end caps. Round end caps for linear, no end caps for quadratic/cubic.

OPTIX_CURVE_ENDCAP_DEFAULT

Nothing in OptixDeviceProperty?

But not the same as Swept-Sphere?

Every Strand Counts: Physics and Rendering Behind Frostbite's Hair



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<https://www.youtube.com/watch?v=o0l2E8SQPGU>

トレンドでもあるが、髪の毛を Triangle Meshではなく、Lineで表現する
合わせて Software Rasterizer (AA)、OIT なども導入される

Every Strand Counts: Physics and Rendering Behind Frostbite's Hair

- Hair Sim
- **Coarse Raster:** Tileに入ってるsegmentのリストを作る
- **Strand-space Shading** ← レイトレへの移行が進んでるので、徐々にLSSの価値が発揮できるかも？
- **Shadow Rendering**
 - Deep Opacity Map: 複数Layerを持つ、光の透過を表現
- **Fine Raster:** Tileごとに、含まれたsegmentを処理
 - Analytic AA
 - OIT ← Primary rayならLSSで正攻法しやすい
- Resolve: 髪以外と合成
- Velocity: Gridで近似

関連資料

- Hair Strands x Rasterization
 - Every Strand Counts: Physics and Rendering Behind Frostbite's Hair
- Hair Strands x Ray Tracing (OptiX)
 - OPTIX_PRIMITIVE_TYPE_ROUND_LINEAR
 - Piecewise linear curve with circular cross-section
 - **Curve** {
 - **Phantom** (OptiX) ~ **Swept Circle**
 - 2018 - Alexander Reshetov, David Luebke - Phantom Ray-Hair Intersector
 - **Rocaps** (OptiX) ~ **Swept Sphere**
 - 2024 - Alexander Reshetov, David Hart - Modeling Hair Strands with Roving Capsules

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<https://raytracing-docs.nvidia.com/optix9/guide/index.html#curves#rocaps-curves>

https://raytracing-docs.nvidia.com/optix9/guide/optix_guide.250703.A4.pdf

> Starting with the Nvidia Blackwell architecture, spheres and linear curves are hardware accelerated

> Phantom uses a swept circle whereas Rocaps uses a swept sphere

> Practically speaking for curves used to represent hair and fur (thin low curvature geometry), the shapes of Phantom and Rocaps are interchangeable

<https://forums.developer.nvidia.com/t/optix-9-rocaps-curve-evaluator/323280>

Alexander Reshetov <https://research.nvidia.com/person/alexander-reshetov>

2024 - **Modeling Hair Strands with Roving Capsules**

https://research.nvidia.com/publication/2024-07_modeling-hair-strands-roving-capsules

2022 - Ray/Ribbon Intersections

https://research.nvidia.com/index.php/publication/2022-07_rayribbon-intersections

2019 - Cool Patches: A Geometric Approach to Ray/Bilinear Patch Intersections

https://research.nvidia.com/publication/2019-03_cool-patches-geometric-approach-raybilinear-patch-intersections

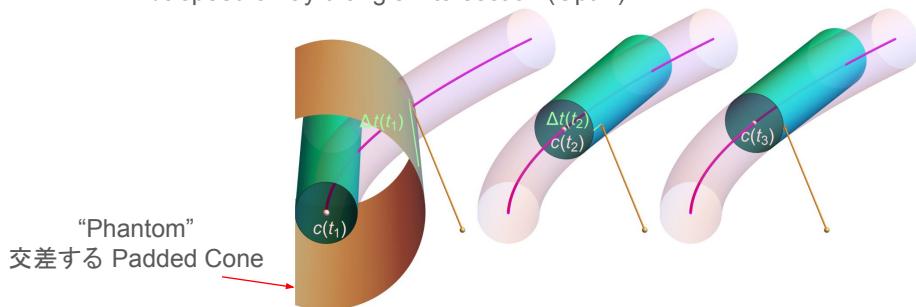
2018 - **Phantom Ray-Hair Intersector**

https://research.nvidia.com/publication/2018-08_phantom-ray-hair-intersector

...

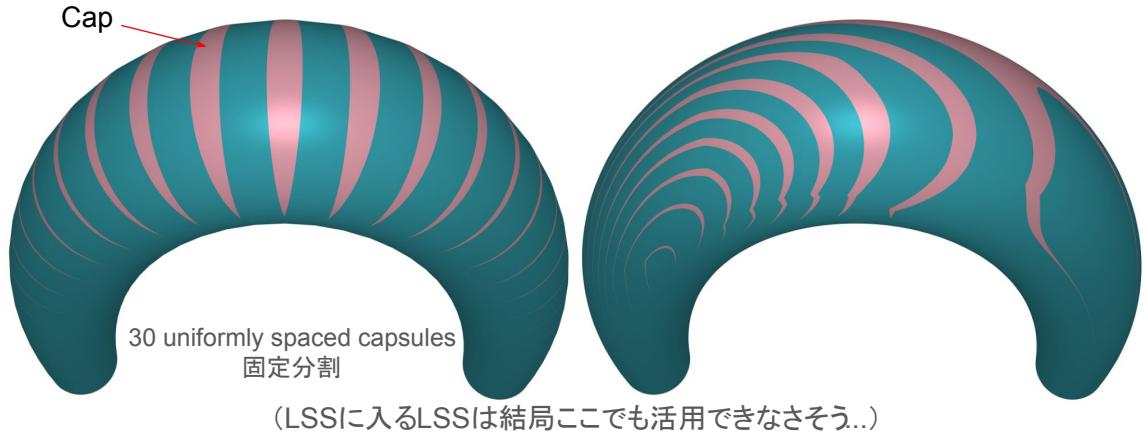
Phantom - Phantom Ray-Hair Intersector

- Ray-Hair 従来手法:
 - 事前に tessellation、コスト高い
 - Closest Point of Approach、間違えるケースがある
- GPUに適した手法を提案
 - “Phantom” 込み、収束するまで交差を繰り返して範囲を絞る
 - $\frac{1}{3}$ speed of ray-triangle intersection (OptiX)



Rocaps - Modeling Hair Strands with Roving Capsules

LSSで近似、ただし、rayごとに配置が最適になるようにループしながら調整
Phantomよりシンプルで高速



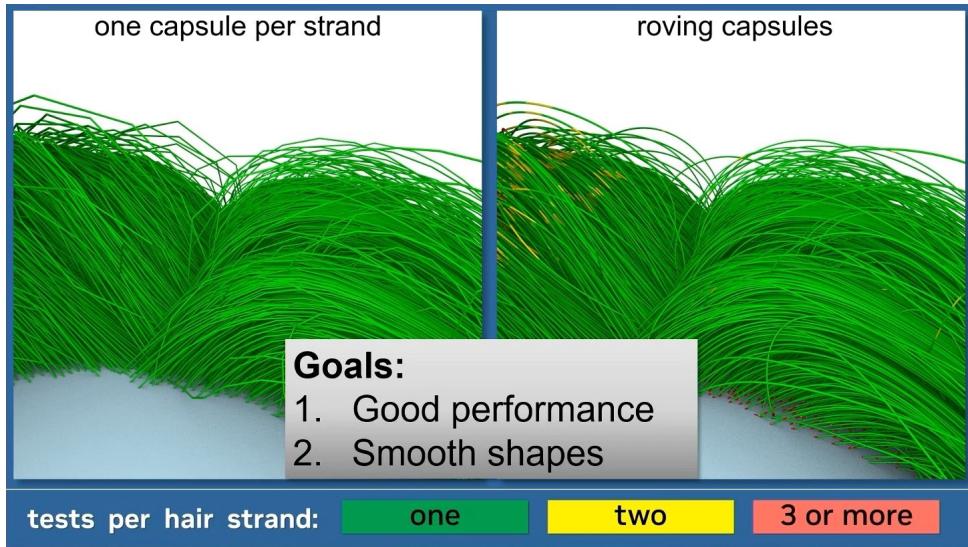
31

10-degree polynomial equation for cubic curves. However, significant accuracy issues with polynomial solvers arise for both circle and sphere volumes when the ray is nearly perpendicular to the curve

Rocaps - Modeling Hair Strands with Roving Capsules



Rocaps - Modeling Hair Strands with Roving Capsules

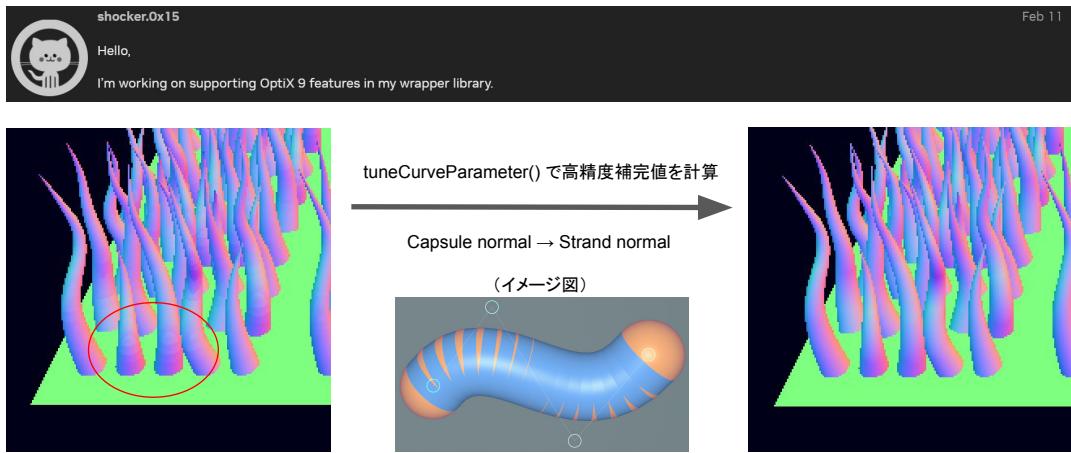


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ただし、Capsuleに分割するコストは無視できない(直感で Capsule hitより重そう)、あまりいい比較ではない気もする

Rocaps - Modeling Hair Strands with Roving Capsules

資料集めているところ、見覚えのある名前が見かけた！ついでに画像を挿借



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<https://forums.developer.nvidia.com/t/optix-9-rocap-curve-evaluator/323280>

<https://www.shadertoy.com/view/4ffXW>

補間パラメータ(及びそれから求める法線)がそのまま滑らかになっているわけではない
髪の毛など細いものが気にしないかもが

反復計算して滑らかにするアルゴリズムも提供されている(実装眺めててかなり重そうな
印象)

感想

LSS API出すならCurveも対応してほしい！