Ogres and Fairies

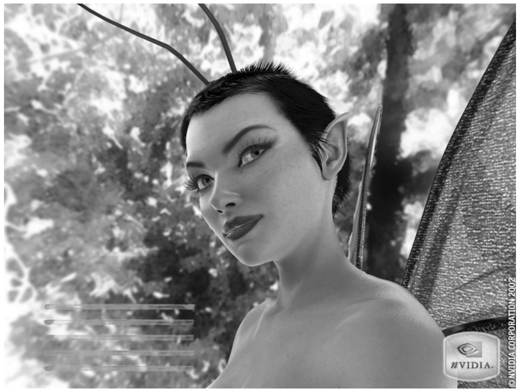
Secrets of the NVIDIA Demo Team

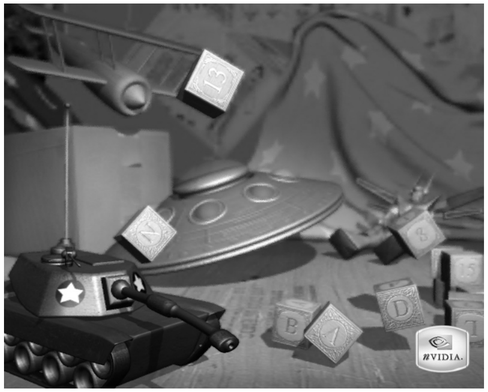
Overview

- Demo engine overview
- Procedural shading for aging effects in “Time Machine”
- Depth of field and post processing effects in “Toys”
- Subdivision surfaces and ambient occlusion shading in “Ogre”
- Advanced skin and hair rendering in “Dawn”
- Questions

The GeForce FX Demo Suite

- 4 demos for the launch of GeForce FX
  - “Dawn”
  - “Toys”
  - “Time Machine”
  - “Ogre”
    (Spellcraft Studio)





Why Do We Do Demos?

- To demonstrate capabilities of new hardware
  - Features
  - Performance
- To provide a practical test bed for new rendering techniques and algorithms
  - Shading teapots is easy
- To inspire application and game developers

NVIDIA Demo Engine

- All demos were developed using the same engine
- NRender – rendering API abstraction
  - Thin layer on top of OpenGL or DirectX 9
  - Uses Cg compiler and runtime for shaders
- NVDemo - object-oriented scene graph library
  - Handles state management, culling, sorting
  - Complete scene can be stored in a single ASCII or binary file
  - Includes Maya and 3DS MAX converters

The Time Machine Demo

Hubert Nguyen

Goals of Time Machine

- Show the potential of a new architecture
  - More data
    - 16 texture inputs
    - 8 texture coordinate interpolators
  - Higher precision (128 bits)
  - More instructions (up to 1024)
    - Shading done in a single pass
  - Faster pixel processing
    - Higher clock speed

- Greater data access & faster processing

A truck ?

- Old pick-up trucks have a wide variety of surfaces.
    - Paint and rusting and oxidizing
    - Wood splintering and fading
    - Chromes being damaged and dirty
    - And more…

Live demo


NAVIGATOR
CONTROLS
DISPLAY
Notes
COLOR
TIME CONTROL
nVIDIA.

A Simple “aging shader” : Chrome

- Aging shaders are multi-layered shaders
  - Several stand-alone effects blended together by a function of time & space
- Case study : chrome
  - 2 layers :
    - Chrome (shiny) layer
    - Rust layer
  - Both are fully lit, bumped and shadowed
  - Each would barely fit on a DX8-class shader

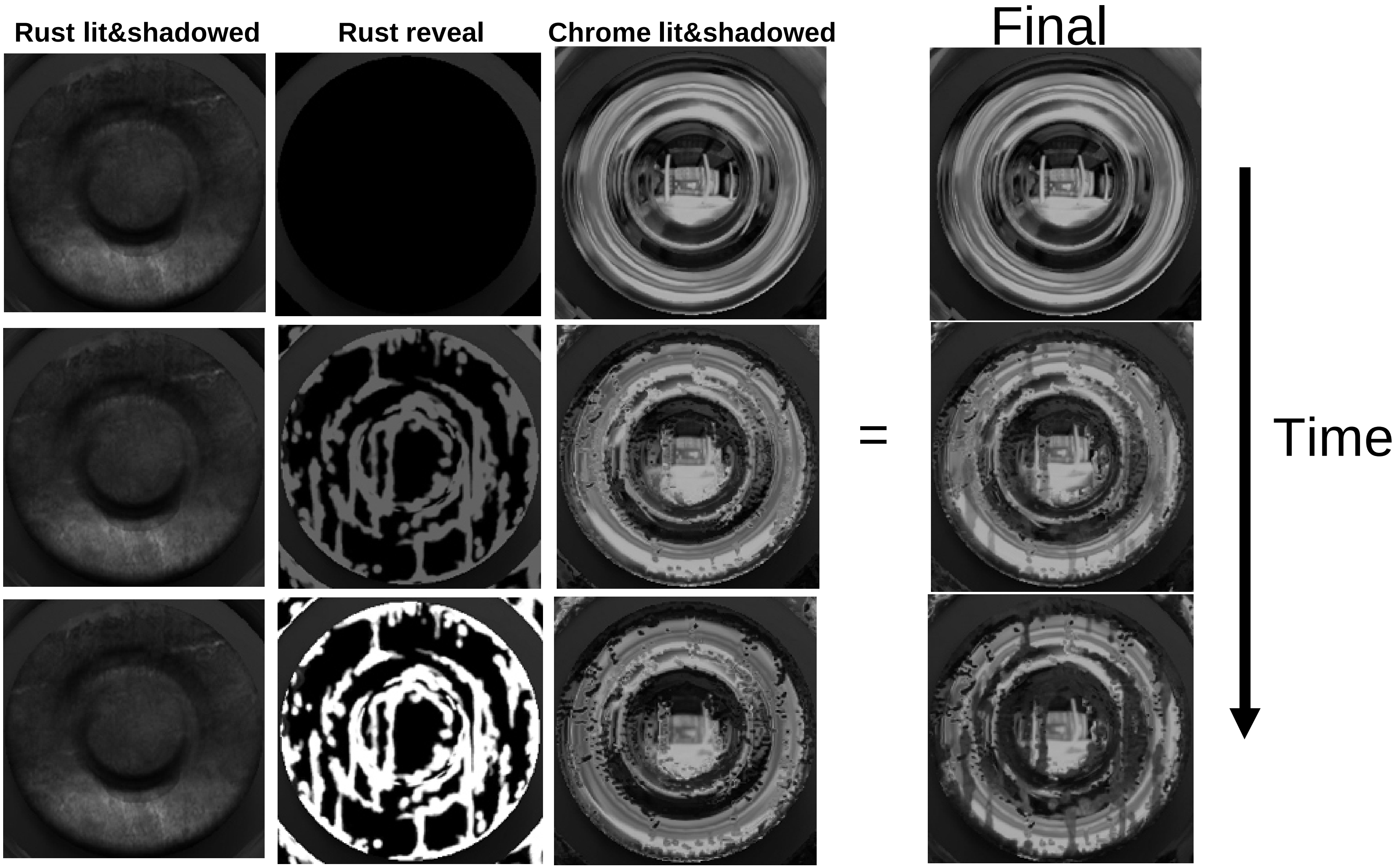
Chrome : getting older

- Chrome still shines over the years
- Reflection fades slightly (dust, dirt, small damages)
- Bumps, scratches & rust shows up

Chrome: aging snapshots

- Full lighting, bump & shadows on all the layers
- Reflection blurred by blending two cube maps
- Bumpy reflection using EMBM, for performance
- “Reveal” texture pinpoints the rust location

Chrome : reveal map



Rust lit&shadowed

Rust reveal

Chrome lit&shadowed

=

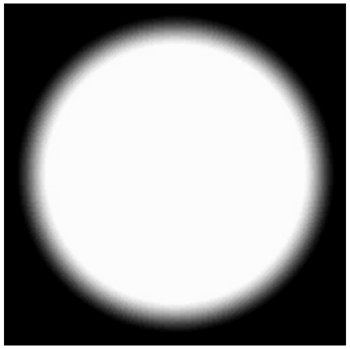
Final

Time

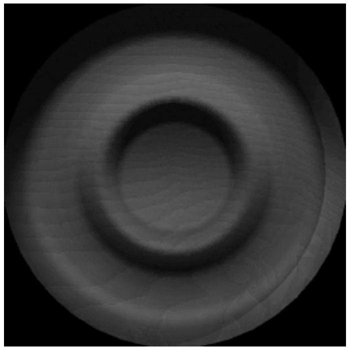
Chrome : texture inputs

Lightmap

Spotmask

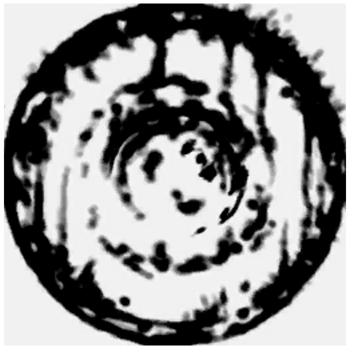


Shadow Map



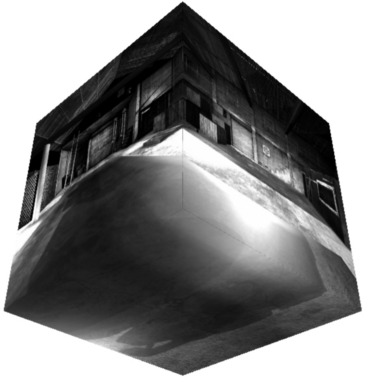
Chrome bump

Rust Reveal

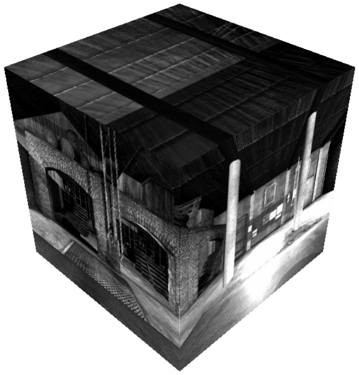


Rust Color

Cube map new



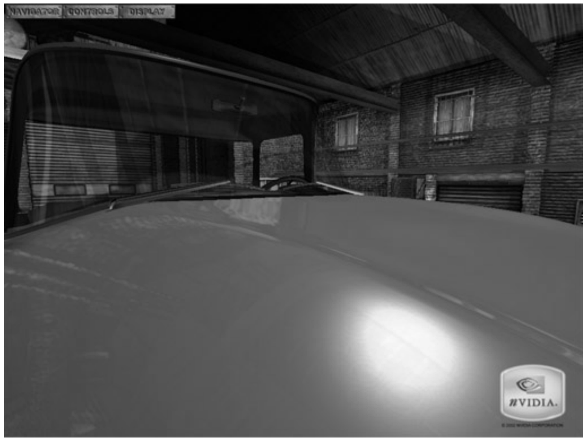
Cube map old



Procedural Shading Effects

Gary King

Time Machine Effects : Paint



Specular color shift

Oxidation

Bubbling

Rusting

Paint textures:

- Paint Color
- Rust LUT
- Shadow map
- Spotlight mask
- Light Rust Color*
- Deep Rust Color*
- Ambient Light*
- Bubble Height*
- Reveal Time*
- New Environment*
- Old Environment*

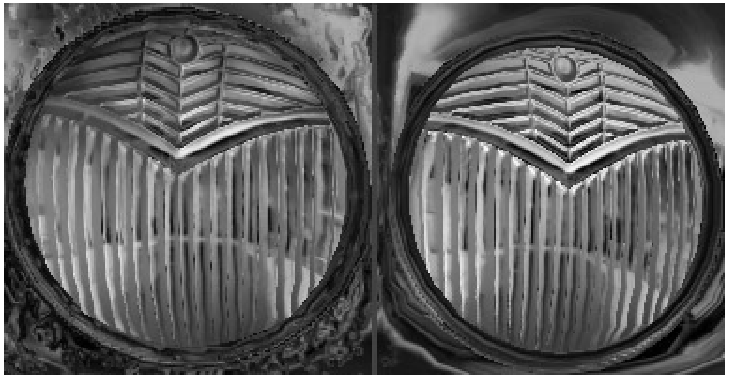
(* = artist created)

60 Pixel Shader instructions, 11 textures

Effects (cont'd) : Wood, Chrome, Glass

Wood fades and cracks
31 instructions, 6 textures

Chrome welts and corrodes
23 instructions, 8 textures



Headlights fog
24 instructions, 4 textures

Procedural or Not?

- Procedural shading normally replaces textures with functions of several variables.
  - Time Machine uses textures liberally.
  - The only parameter to our shaders is time.
- Artists love sliders when finding a look, but hate sliders when creating one.
  - Demos (and games) are art-driven – don’t sacrifice image quality to satisfy technical interests.
- Turning everything into math is expensive
- Time Machine’s solution
  - Give artist direct control (textures) over final image, use functions to control transitions

Techniques : Faux-BRDF Reflection

- Many automotive paints exhibit a color-shift as a function of the light and viewer directions.
  - This effect has been approximated with analytic BRDFs (Lafortune's cosine lobes)
  - And measured by Cornell University's graphics lab
- Goal: Incorporate this effect in real-time
  - BRDF factorization [McCool, Rusinkiewicz] is one method to use this data on graphics hardware
    - Represents BRDF as product of multiple 2D textures
    - Closely approximates the original BRDFs
    - Rotated/projected axes hard to visualize, editing textures is unintuitive

Techniques : Faux-BRDF Reflection 2

- Our solution: project BRDF values onto a single 2D texture, and factor out the intensity
  - Compute intensity in real-time, using $(N.H)^s$
  - Texture varies slowly, so it can be low-res (64x64).
  - Anti-aliasing texture fixes laser noise at grazing angles
  - For automotive paints, N.L and N.H work well for axes.
  - Not physically accurate, but fast and high-quality.
  - Easy for artists to tweak.

Dupont Cayman lacquer

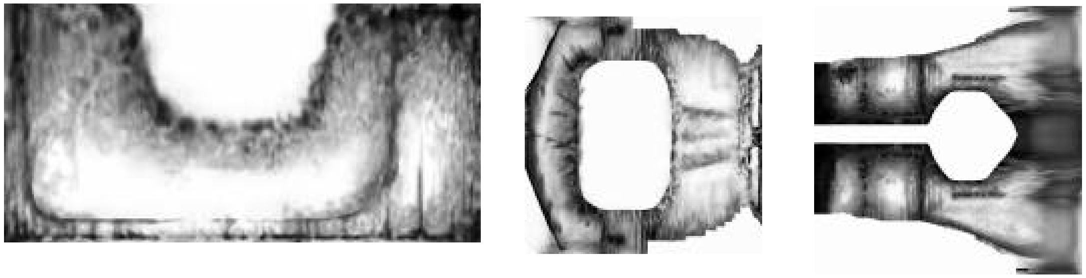
Mystique lacquer

Techniques : Reveal and Velocity maps

- **Artists do not want to paint hundreds of frames of animation for a surface transition (e.g., paint->rust)**
  - **Ultimately, effect is just a conditional:**

    if (time > n) color = rust; else color = paint;
  - **Or an interpolation between a start and end point**

    paint = interpolate(paint, bleach, s*(time-n));
  - **So all intermediate values can be generated.**
  - **For continuous effects, use velocity (dXdT) maps**
  - **Can be stored in alpha in a DXT5 texture.**



Techniques : Dynamic Bump mapping

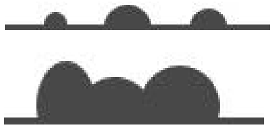
- Scaling a normal map by a constant doesn't change surface topology.

$$\iint N(x,y)\partial x\partial y = h(x,y)$$

$$\iint cN(x,y)\partial x\partial y = ch(x,y)$$

- To change surface topology, the height map needs to be updated every frame, and the normals recomputed from that (chain rule).

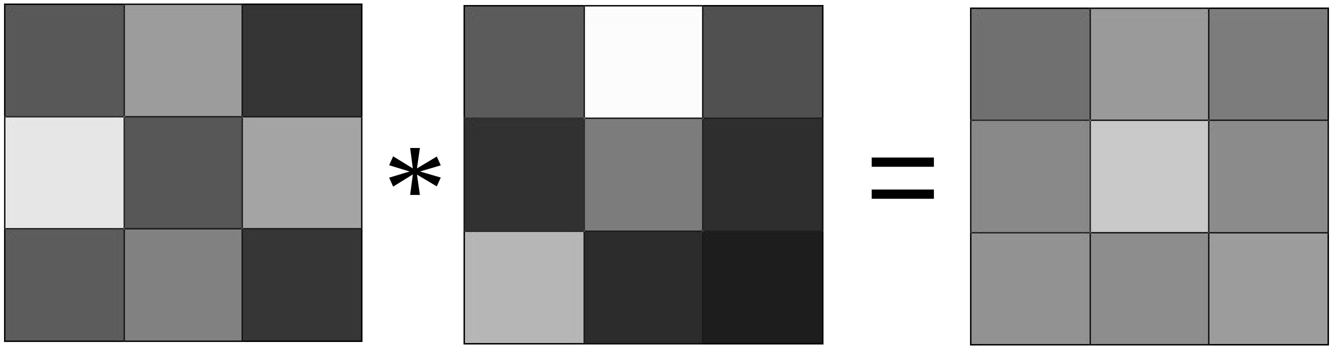
$$N'(x,y) = \frac{\partial h'(x,y)}{\partial x\partial y}$$



- This is analogous to techniques that use the GPU to solve partial differential equations.

Techniques : Dynamic Bump mapping 2

- **By multiplying each object’s height map by a growth function (dXdT map) and recomputing the normals, we created a bubble effect that allows bubbles to grow, merge, and decay realistically.**
  - **As a side benefit, all normals are computed from mip-mapped height maps.**



Height map

Growth factor at *t*=*n*

New normals

$$N'(x,y,t) = \frac{\partial h(x,y)g(x,y,t)}{\partial x \partial y}$$

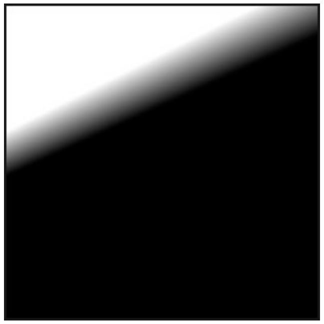
Performance Concerns

- Executing large shaders is expensive.
  - First rule of optimization: Keep inner loops tight
  - Shaders *are* the inner loop, run >1M times per frame.
- But graphics cards have many parallel units
  - Vertex, fragment, and texture units
  - Modern GPUs do a great job of hiding texture latency
  - Bandwidth is unimportant in long shaders
    - Time Machine runs at virtually the same framerate on a 500/500 GeForceFX as it does on a 500/400 or 500/550
  - So not using textures is wasting performance!

Performance Concerns…

- Convert arithmetic expressions into textures
  - If…
    - 8 (RGBA) or 16 (HILO) bit precision sufficient
    - Approximately linear, above some resolution
    - Depends on a limited number of variables
  - LUTs = 2x performance in Time Machine
    - Rust Interpolation
      - Computes the normalized difference of reveal maps.
      - Dependent on current and reveal time, blends 2 textures.
    - Surround Maps
      - Recomputing the normal requires heights of neighbors
      - Each height is only 1 8-bit component
      - Instead of 4 dependent fetches, we can pack

$$\mathbf{S}(s,t) = [\ \mathbf{H}(s-1,\ t),\ \mathbf{H}(s+1,\ t),\ \mathbf{H}(s,t-1),\ \mathbf{H}(s,t+1)\ ]$$



Performance Concerns…

- Defer common operations
  - Lighting for each effect layer is $(K_s*(N.H)^b + K_d*(N.L))*v$
    - Compute normal, select K_s, b, and K_d based on the per-pixel layer, and light once (don’t call pow() more times than absolutely necessary!).
- Invisible results don’t need to be correct.
  - Example: The texture coordinates for the specular color-shift don’t matter once the paint has rusted

Summary

- We aren’t limited to vertex animation anymore
- Shaders should provide artists the inputs they need to create the effects they want
  - Start and end points are critical to overall quality
  - In-betweens are less-so, and more tedious to paint
- Once you have the right effect, look for shortcuts
  - 500 arithmetic instructions will not run in real-time
  - Don’t be afraid of textures
- Be creative – programmable hardware has near-limitless effect and optimization opportunities.

Further Reading

- M. McCool, J. Ang and A. Ahmad, “Homomorphic Factorization of BRDFs for High-Performance Rendering, Computer Graphics (Proceedings of SIGGRAPH 01), pp. 171-178 (August 2001, Los Angeles, California).
- P. Hanrahan and J. Lawson, “A Language for Shading and Lighting Calculations”, Computer Graphics (Proceedings of SIGGRAPH 90), 24 (4), pp. 289-298 (September 1990, Dallas, Texas).
- Simon Rusinkiewicz, “A New Change of Variables for Efficient BRDF Representation,” Rendering Techniques (Proceedings of Eurographics Workshop on Rendering 98).

Further Reading

- **NVIDIA Developer Website**
  - **http://www.nvidia.com/developer**
- **Cornell University Program of Computer Graphics Light Measurement Laboratory**
  - **http://graphics.cornell.edu/online/measurements**

Depth of Field in the Toys Demo

Fun with Realtime Post-Processing

What is Depth of Field?

- In computer graphics, it’s easier to pretend we have a perfect pinhole camera, with no lens or film artifacts.
- Real lenses have area, and therefore only focus properly at a single depth.
- Anything in front of this or behind this appears blurred, due to light rays from this point not focusing on a single point on the film.
- For a circular lens, each point in space projects to a circle on the film, called the circle of confusion.

Simple Depth of Field

- **Render scene to color and depth textures**
- **Generate mipmaps for color texture**
- **Render fullscreen quad with simpledof shader:**
  - **Depth = tex(depthtex, texcoord)**
  - **Coc *(circle of confusion)* = abs(depth*scale + bias)**
  - **Color = txd(colortex, texcoord, (coc,0), (0,coc))**
- **Scale and bias are derived from the camera:**
  - **Scale = (aperture * focaldistance * planeinfocus * (zfar – znear)) / ((planeinfocus – focaldistance) * znear * zfar)**
  - **Bias = (aperture * focaldistance * (znear – planeinfocus)) / ((planeinfocus * focaldistance) * znear)**

Artifacts: Bilinear Interpolation/Magnification

- Bilinear artifacts in extreme back- and near-ground
- Solution: multiple jittered samples
  - Even without jittering, a 4 or 5 sample rotated grid pattern brings smaller artifacts under control
  - Larger artifacts need jittered samples, and more of them
  - Then it’s just a tradeoff between noise from the jittering and bilinear interpolation artifacts
  - (and of course the quality/performance tradeoff with number of samples)

Noise vs. Interpolation Artifacts

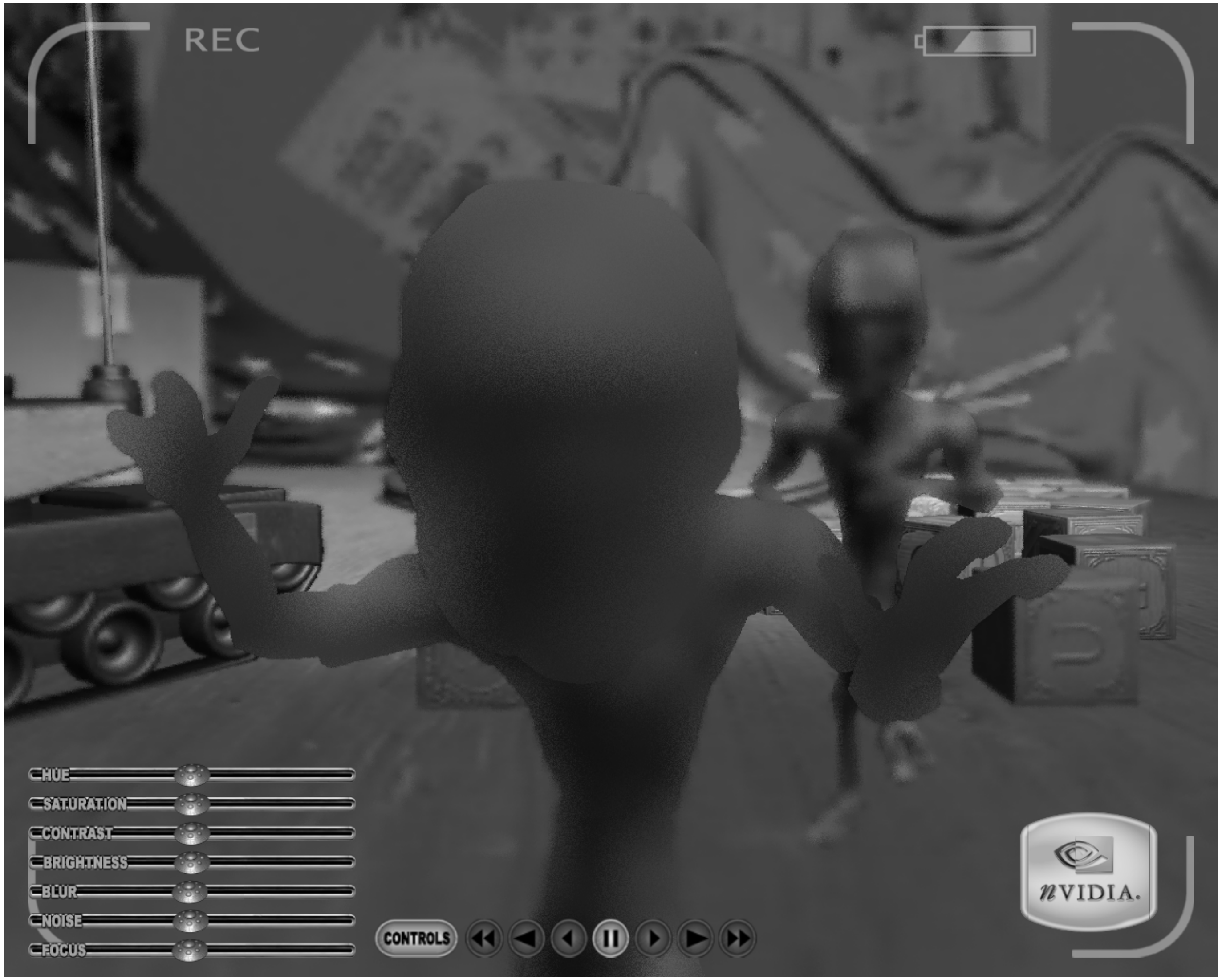
With Noise

Without Noise

Artifacts: Depth Discontinuities

- Near-ground (blurry) pixels don’t properly blend out over top of mid-ground (sharp) pixels
- Easy solution: Cheat!
  - Either don’t let objects get too far in front of the plane in focus, or blur everything a little more when they do – soft edges help hide this fairly well.
- Harder solution: Depth imposters.
  - For plane-like objects, you can render an imposter extended to the extents of the blur, use a color texture of just that object, and the depth of the imposter, and then apply the simple technique

Depth Discontinuities



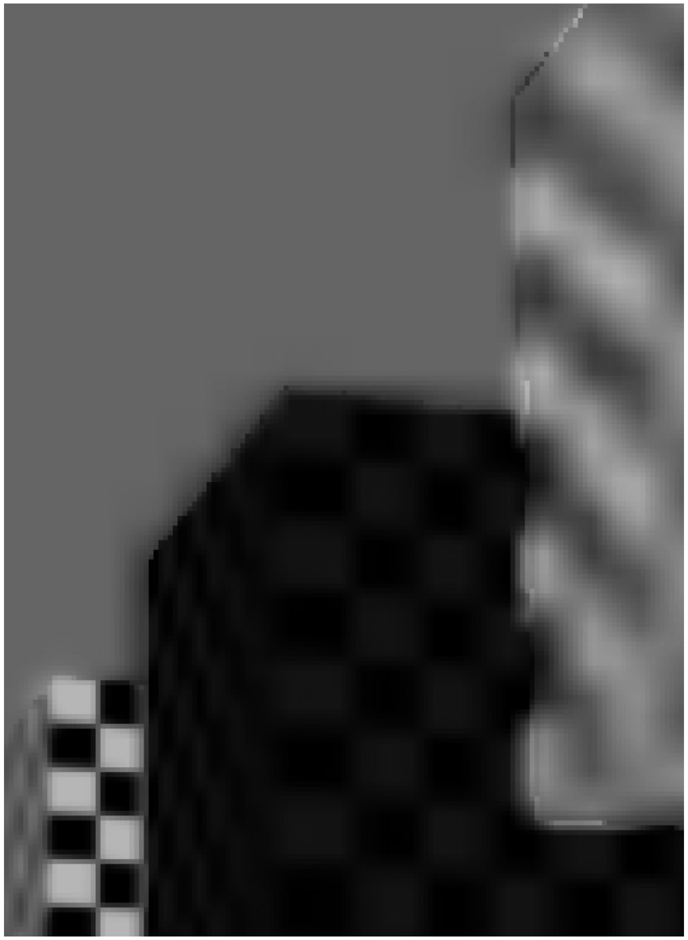
Artifacts: Pixel Bleeding

- Mid-ground (sharp) pixels bleed into back- and fore-ground (blurry) pixels
- Solution: integrate standard layers technique
  - Split the scene into layers, and render each separately into its own color and depth texture
  - Then blend these layers on top of each other, using the simple depth of field technique
  - Fortunately, this tends not to be much of a problem except in artificial situations

Simple DOF Vs. Layered DOF

Layered DOF

Simple DOF



Advanced Depth of Field

- Auto-mipmap generation vs. intelligent mipmaps
  - It may be possible to generate “smart” mipmaps that blur with their neighbors based upon their coc.
  - It feels slightly easier to split the scene into behind and in front of the plane in focus, but not much…
- Splatting and forward warping techniques
  - This is probably the most intuitive way of thinking about depth of field, but the least hardware-friendly.
  - You could render a particle per pixel of the color texture, sized based upon its coc, and blend them
  - PDR and vertex programs help, but it’s still

    a LOT of particles!

Fun With Color Matrices

- **Since we're already rendering to a full-screen texture, it's easy to muck with the final image.**
- **To color shift, rotate around the vector (1,1,1)**
- **To (de)saturate, scale in the plane (1,1,1,d)**
- **To change brightness, scale around black: (0,0,0)**
- **To change contrast, scale around midgrey: (.5,.5,.5)**
- **These are all matrices, so compose them together, and apply them as 3 dot products in the shader**

Original Image

Colorshifted Image

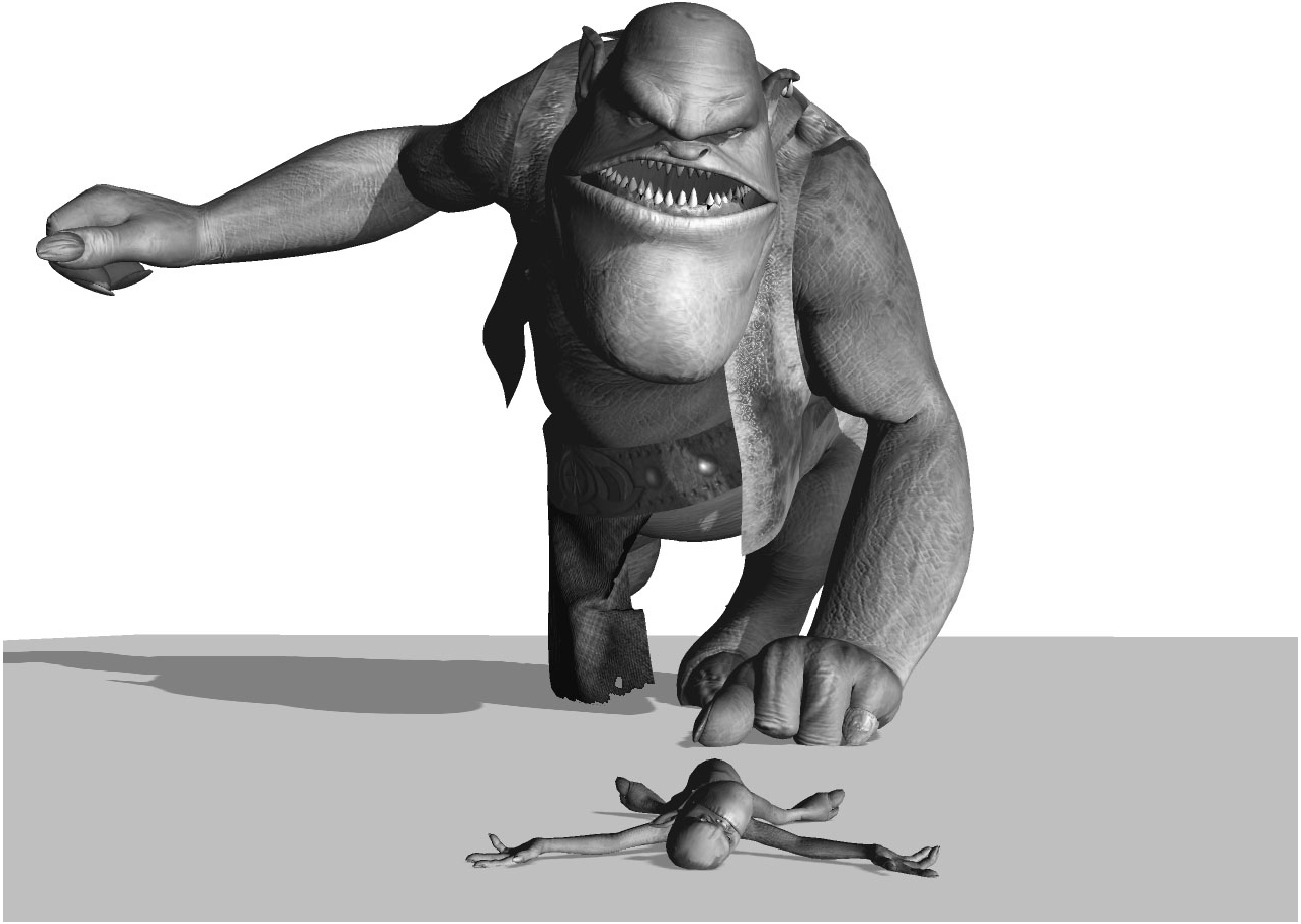
Black and White Image

Further Reading

- **Paul Haeberli, “Matrix Operations for Image Processing”: http://www.sgi.com/grafica/matrix/**
- **Richard Cant, et al, “New Anti-Aliasing And Depth of Field Techniques For Games”: http://ducati.doc.ntu.ac.uk/uksim/dad/webpagepapers/Game-18.pdf**
- **Jurriaan Mulder, Robert van Liere, “Fast Perception-Based Depth of Field Rendering”: http://www.cwi.nl/~robertl/papers/2000/vrst/paper.pdf**
- **Tomas Arce, Matthias Wloka, “In Game Special Effects and Lighting”: http://developer.nvidia.com/docs/IO/2714/ATT/GDC2002_InGameSpecialEffects.pdf**

Inside the “Ogre” Demo

Simon Green



Overview

- Introduction
- Subdivision surfaces
- Shading
- Ambient occlusion
- Out-takes

The “Ogre” Demo

- A real-time preview of Spellcraft Studio’s in-production short movie “Yeah! The Movie”
  - Created in 3DStudio MAX
  - Character Studio used for animation, plus Stitch plug-in for cloth simulation
  - Original movie was rendered in Brazil with global illumination
  - Available at: www.yeahthemovie.de
- Our aim was to recreate the original as closely as possible, in real-time

The Original Short Movie

What are Subdivision Surfaces?

- A curved surface defined as the limit of repeated subdivision steps on a polygonal model
  - We used the Catmull-Clark subdivision scheme
- Subdivision surfaces do not have the continuity problems associated with some other surface representations – e.g. Bezier triangles
- MAX, Maya, Softimage, Lightwave all support forms of subdivision surfaces
- Subdivision surfaces are beginning to replace NURBS for character modeling in movie production (e.g. Weta)

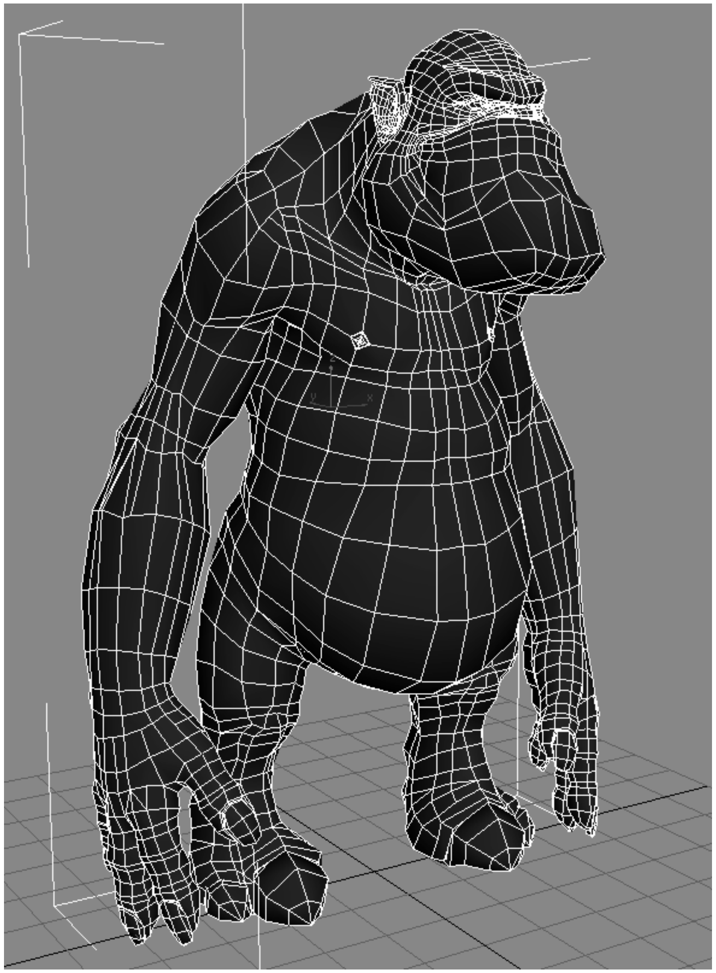
Why Use Subdivision Surfaces?

- Content
  - Characters were modeled with subdivision in mind (using 3DS MAX “MeshSmooth” modifier)
- Scalability
  - wanted demo to be scalable to lower-end hardware
- “Infinite” detail
  - Can zoom in forever without seeing hard edges
- Animation compression
  - Just store low-res control mesh for each frame
- Test bed for future hardware support

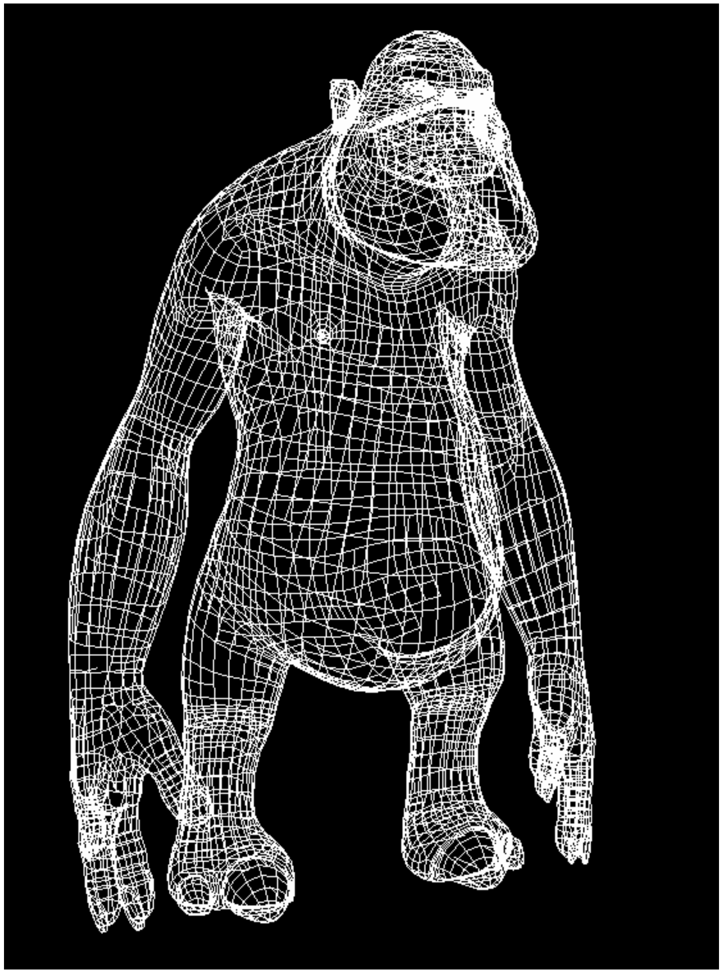
Realtime Adaptive Tessellation

- Brute force subdivision is expensive
  - Generates lots of polygons where they aren’t needed
  - Number of polygons increases exponentially with each subdivision
- Adaptive tessellation
  - subdivides based on screen-space flatness test
  - Guaranteed crack-free
  - Generates normals and tangents on the fly
  - Culls off-screen and back-facing patches
  - CPU-based (uses SSE were possible), GPU assisted
  - Written by Michael Bunnell of NVIDIA
- We will release this as a library soon

Control Mesh vs. Subdivided Mesh

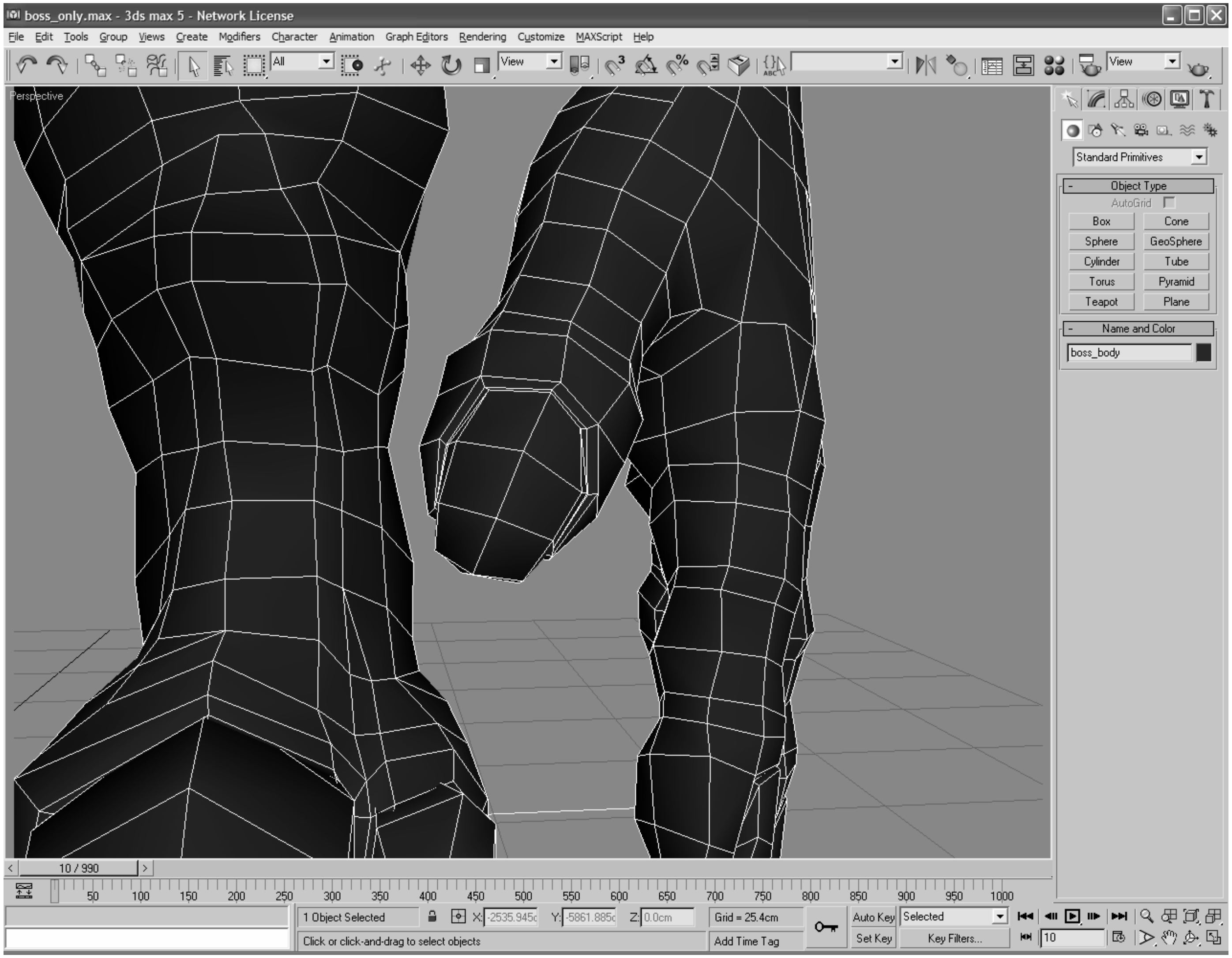


4000 faces



17,000 triangles

Control Mesh Detail (3DS MAX)



boss_only.max - 3ds max 5 - Network License

Standard Primitives

Name and Color: boss_body

10 / 990

1 Object Selected

X: -2535.945c Y: -5861.885c Z: 0.0cm

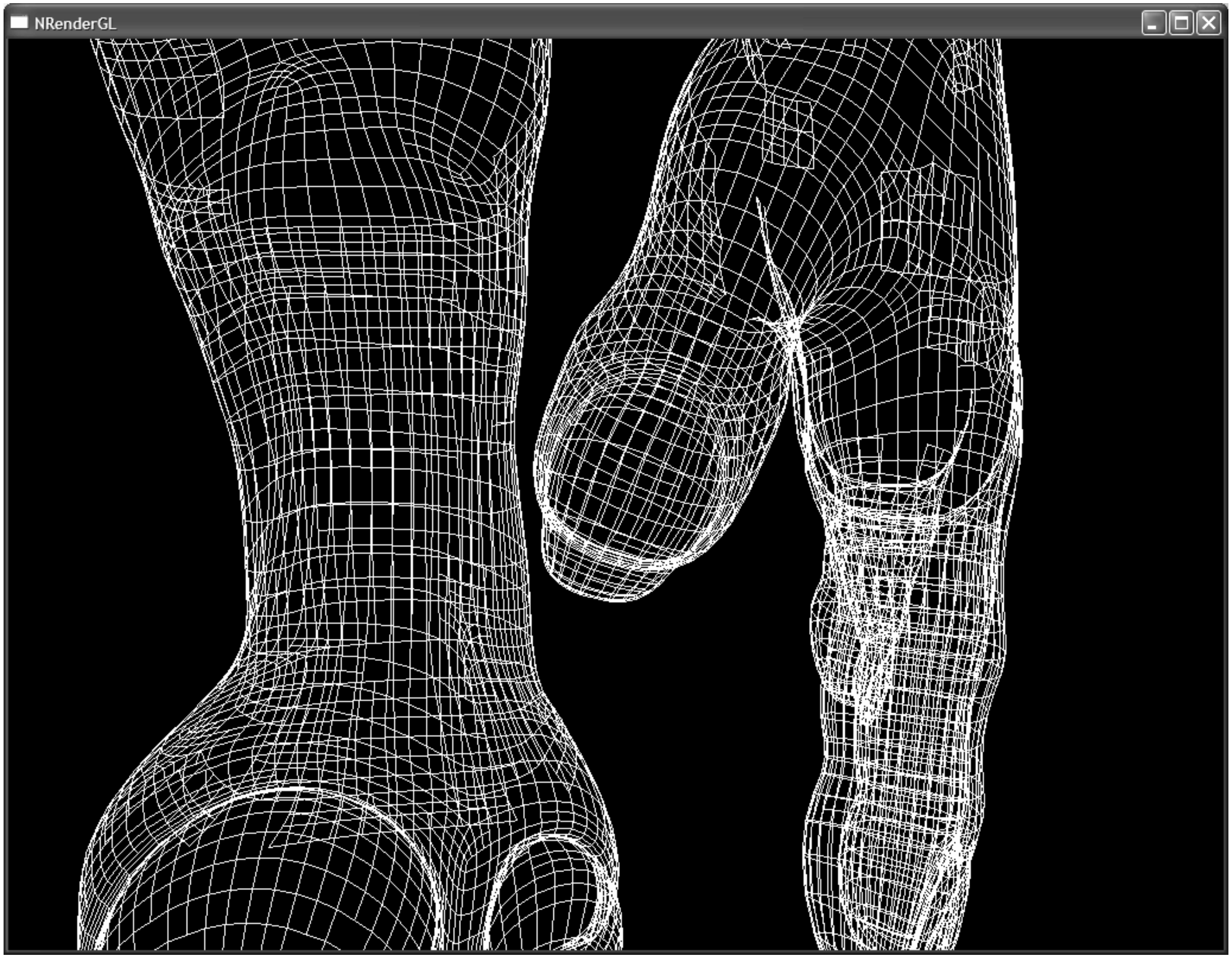
Grid = 25.4cm

Auto Key: Selected

10

Click or click-and-drag to select objects

Subdivided Mesh Detail (Realtime)



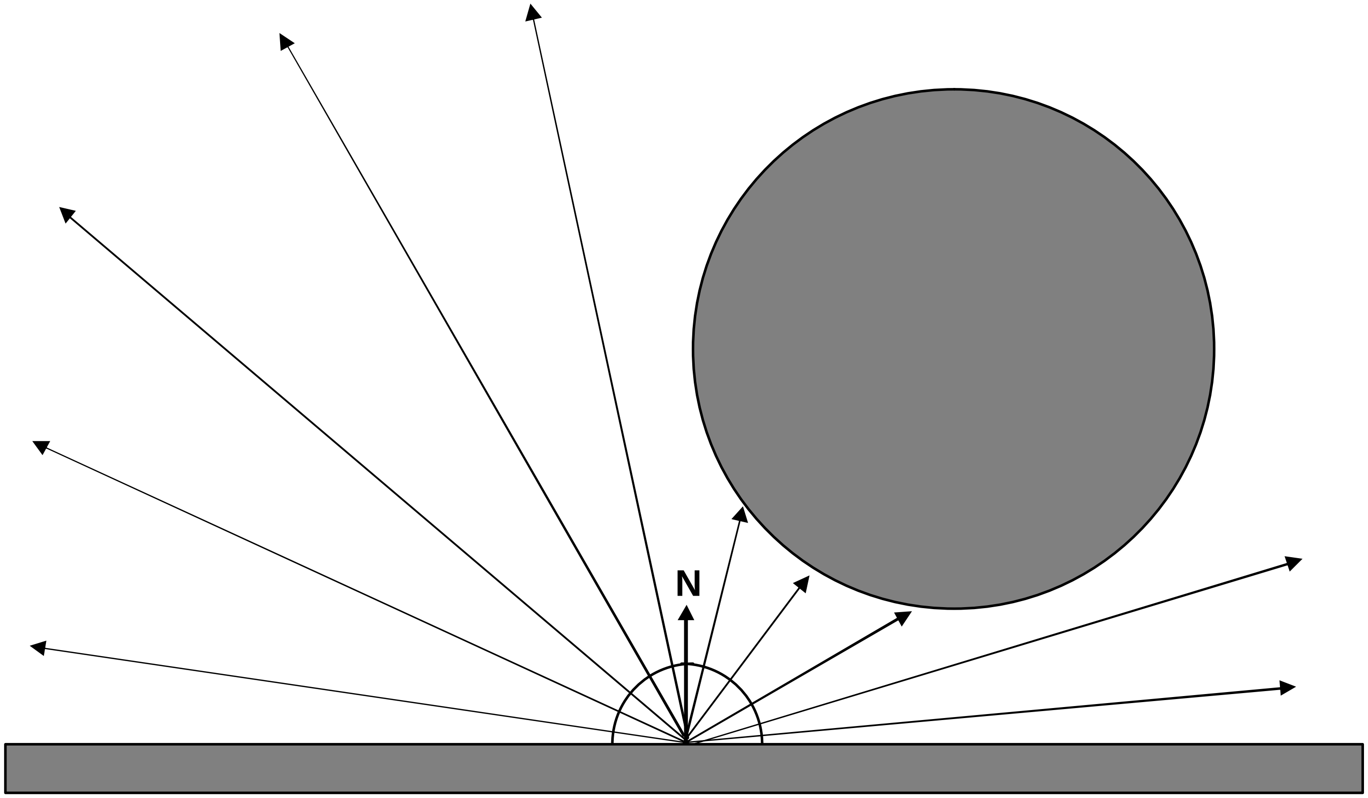
Shading

- **Skin shader**
  - **Uses 4 textures:**
    - **Color map, bump map, specular map, shadow map**
  - **Uses Blinn-style bump mapping (not tangent space)**
    - `float3 bump = f3tex2D(bumpTex, v2f.texcoord)`
    -
      ```
      float3 bumpedNormal = normalize(normal +
        bumpScale * (bump.x*v2f.tangent + bump.y*v2f.binormal)));
      ```
  - **Ambient term comes from pre-calculated occlusion**
- **Shadows**
  - **Uses hardware shadow map support**
  - **2k x 2k resolution**
  - **Uses 8 jittered samples on floor to soften edges**

Ambient Occlusion Shading

- Helps simulate the global illumination “look” of the original movie
- Self occlusion is the degree to which an object shadows itself
  - Simulates a large spherical light surrounding the scene
  - Popular in production rendering – e.g. Pearl Harbour (ILM), Stuart Little 2 (Sony)
- Occlusion is pre-calculated for every vertex in control mesh, interpolated by subdivision code
- Occlusion tool written by Eugene D’Eon, University of Waterloo

Occlusion




NRenderGL
display
navigation
controls
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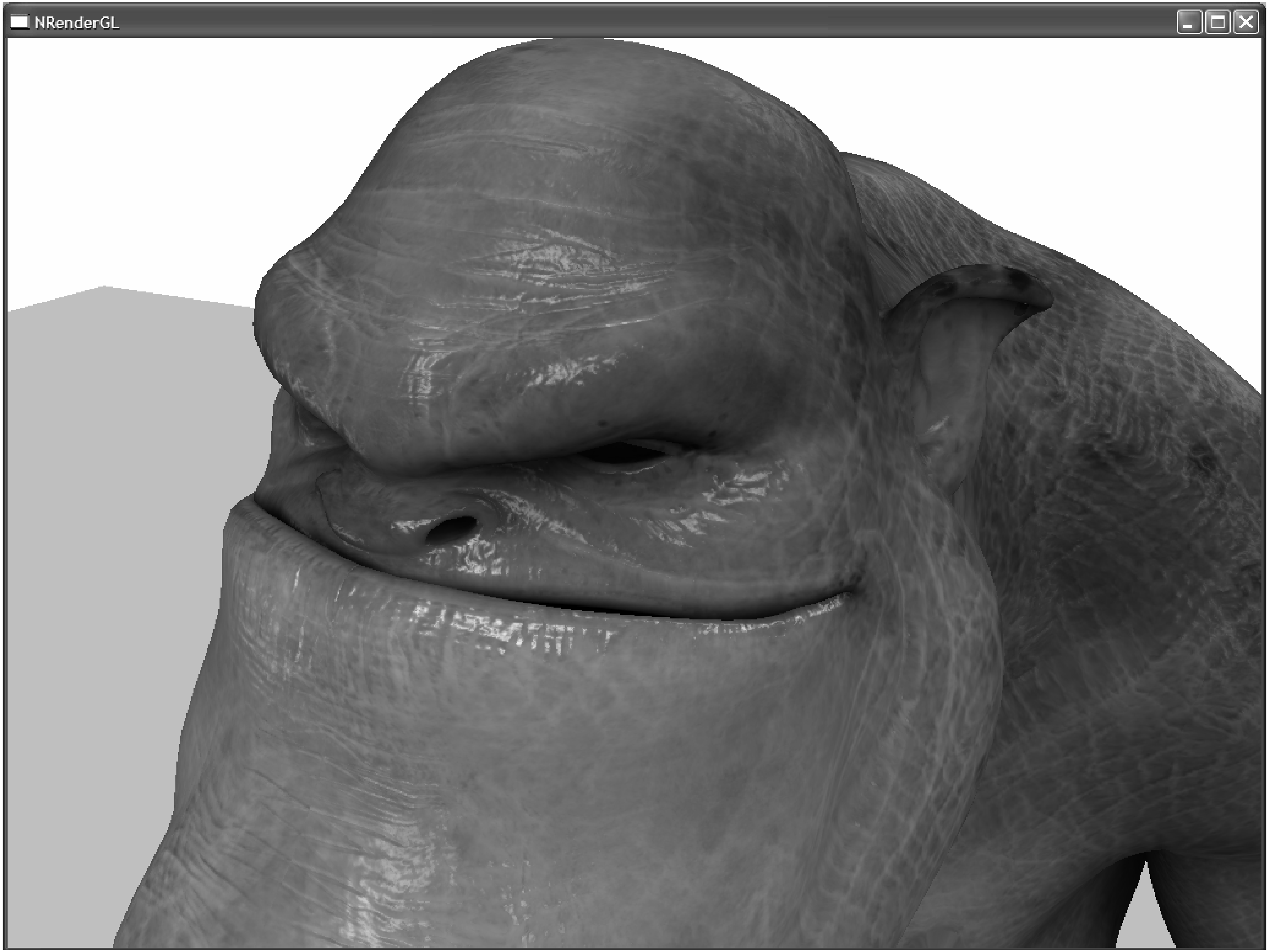

NRenderGL

Future Work

- Displacement mapped subdivision surfaces
- Optimize subdivision
- Bent normals
- Spherical harmonic lighting

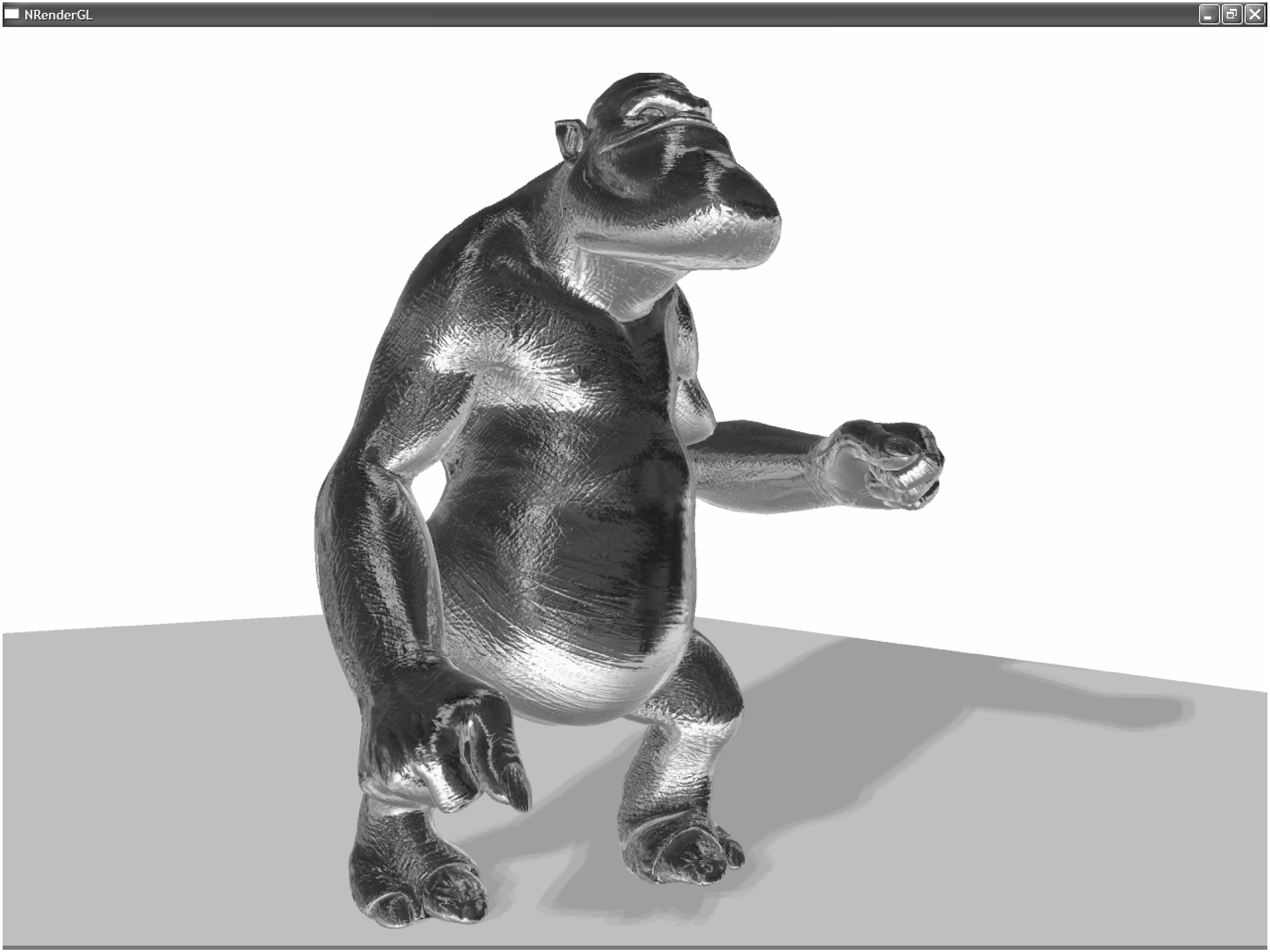
Acknowledgements

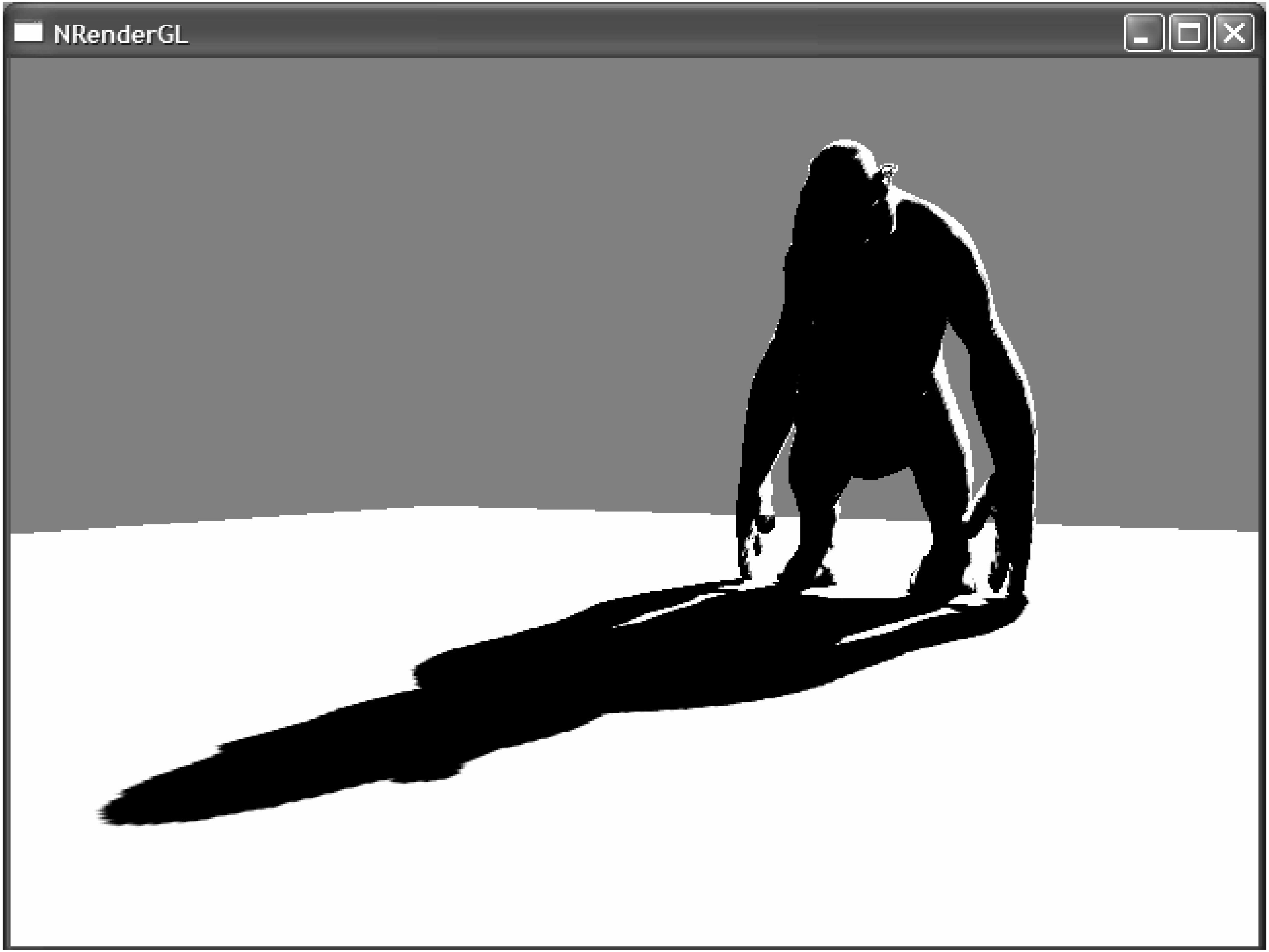
- Special thanks to:
  - Vadim Pietrzynski and Matthias Knappe of Spellcraft Studio
  - Michael Bunnell
  - Eugene D’Eon

References

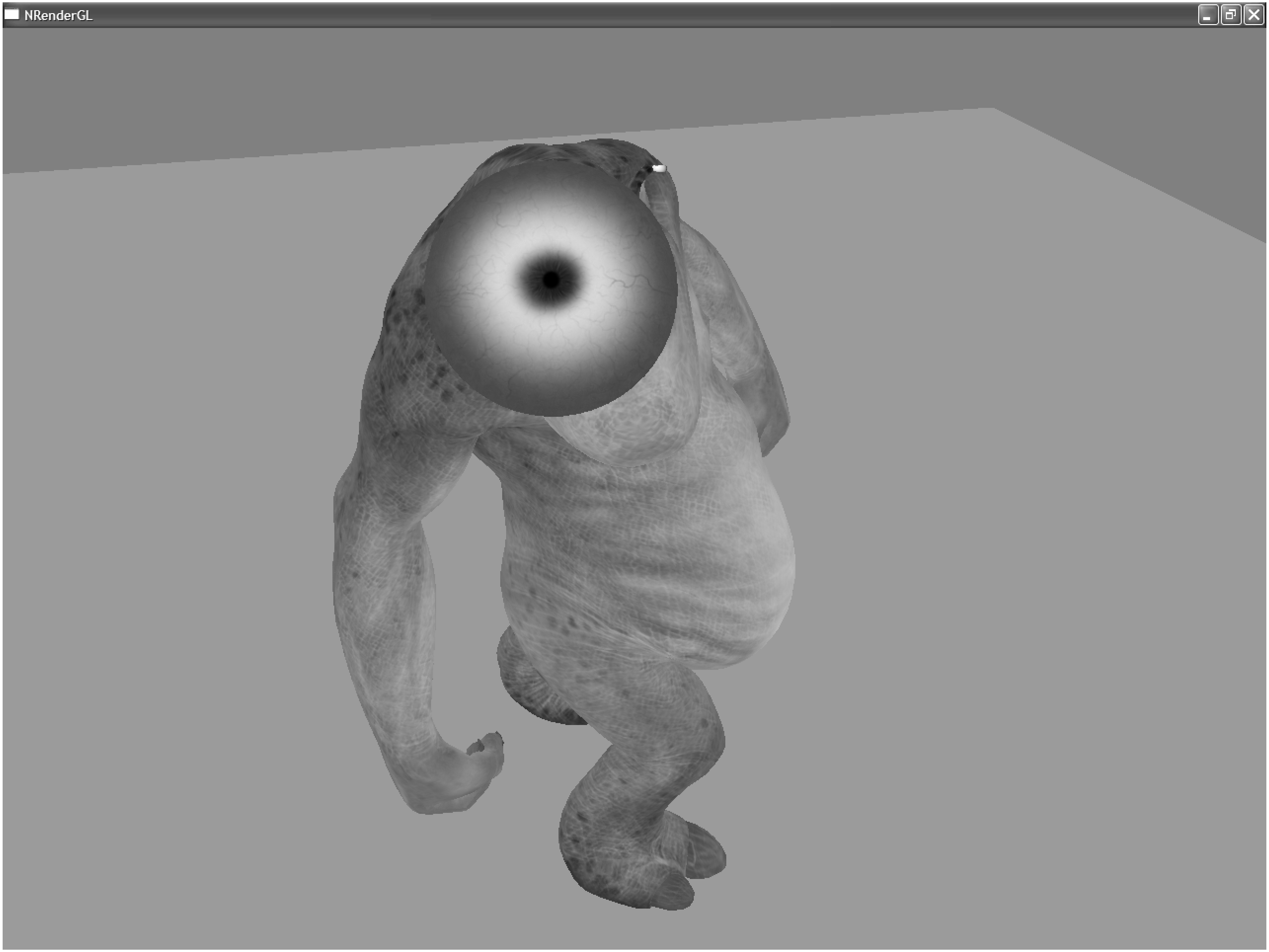
- http://graphics.cs.ucdavis.edu/CAGDNotes/
- http://www.subdivision.org
- "*Production-Ready Global Illumination*", Hayden Landis, Industrial Light & Magic, Siggraph 2002 Renderman Course Notes http://www.renderman.org/RMR/Books/index.html

Outtakes


NRenderGL



NRenderGL


NRenderGL

Animation and Shading in “Dawn”

Curtis Beeson


nVIDIA.

Overview – The Devil is in the Details

- Introduction
- Vertex Shade
  - Blendshape
  - Indexed Ski
  - Fragment S
- Fragment Sha
  - Skin Shade
  - Skin Shade
  - Simplificati
- Summary

Dawn Demo - Introduction

- Content created in Alias/Wavefront Maya
  - Modeling, texturing, and animation
  - Character setup directly from Maya
- Hair created in Simon Green’s hair combing tool
- Occlusion generated using Eugene D’Eon’s tool
- Motion capture performed by House of Moves
- Realtime engine is in-house “Demo Engine”
  - Vertex and Fragment shaders read as data
  - Vertex shaders procedurally generated
  - Code for engine and art path available

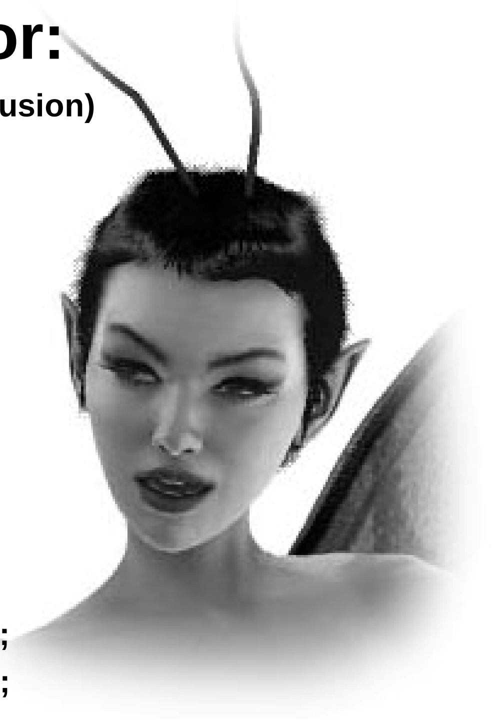
Vertex Shader: Blendshapes (1/2)

- Collected from Maya “Blendshape” node
- 50 faces
  - 30 emotion faces (angry, happy, sad…)
  - 20 modifiers (left eyebrow up, right smirk …)
- Each target stored as difference vector
- A blendshape is a single multiply-add
  - Per *active* blend target
  - Per attribute
  - Result is a weighted sum of all *active* targets
- An *active* blendshape takes vertex attributes
  - 12 * (coodinate)
  - 6 * (coordinate + normal)
  - 4 * (coordinate + normal + tangent)

Vertex Shader: Blendshapes (2/2)

- In the ApplicationToVertex connector:

```
// normals & normal targets are float4(normal.x, normal.y, normal.z, occlusion)
struct a2vConnector : application2vertex {
        float4 coord;               float4 normal;
        float3 coordMorph0;         float4 normalMorph0;
        float3 coordMorph1;         float4 normalMorph1;
        float3 coordMorph2;         float4 normalMorph2;
        …
}
```



- In the vertex shader body:

```
float4 objectCoord = a2v.coord;
objectCoord.xyz = objectCoord.xyz + morphWeight0 * a2v.coordMorph0;
objectCoord.xyz = objectCoord.xyz + morphWeight1 * a2v.coordMorph1;
objectCoord.xyz = objectCoord.xyz + morphWeight2 * a2v.coordMorph2;
…
float4 objectNormal = a2v.normal;
objectNormal = objectNormal + morphWeight0 * a2v.normalMorph0;
objectNormal = objectNormal + morphWeight1 * a2v.normalMorph1;
objectNormal = objectNormal + morphWeight2 * a2v.normalMorph2;
…
```

Vertex Shader: Indexed Skinning (1/2)

- Mesh exported in “Bind Pose”
- Skinning Vertex Data
  - Float4 channel(s) for indices
  - Float4 channel(s) for weights
  - Sort from strongest to weakest we
- “Accumulated Matrix” Skinning
  - Accumulates all used bones and w
  - Faster when doing >2 vertex quantities and >2 bones
  - Not intuitive, but the math works out

Vertex Shader: Indexed Skinning (2/2)

- What is a skinning matrix?
  - To global space(skinWorld): Model * $\text{Model}^{-1}_{\text{bindpose}}$
  - To eye space(skinEye): Model * $\text{Model}^{-1}_{\text{bindpose}}$ * View
- How to accumulate skinWorld or skinView:

```
float4x4 accumulate_skin(float4x4 bones[98], float4 boneWeights0, float4 boneIndices0){
        float4x4 result = boneWeights0.x *bones[boneIndices0.x];
        result = result +  boneWeights0.y *bones[boneIndices0.y];
        result = result +  boneWeights0.z *bones[boneIndices0.z];
        result = result +  boneWeights0.w*bones[boneIndices0.w];
        return result;
}
```

- Skinning is now just a single matrix multiply

```
float4x4 skinWorld   = accumulate_skin(skinWorldMatrices, a2v.boneWeights0, a2v.boneIndices0);
float3 worldCoord    = mul(skinWorld, a2v.coord);
float3 worldNormal   = vecMul(skinWorld, a2v.normal);
float3 worldTangent = vecMul(skinWorld, a2v.tangent);
```

Vertex Shader: Fragment Shader Setup

- **WorldEyeDirection**

  normalize(worldCoord-worldEyePos)

- **TangentToWorld Matrix**

  (Inverse of worldToTangent = transpose

  ```
  | worldTangent.x        worldBinormal.x
  | worldTangent.y        worldBinormal.y
  | worldTangent.z        worldBinormal.z
  ```

- **Blood Transmission Te**

  ```
  float VdotN            = dot(worldEyeD
  float VdotNcomp        = 1.0f - VdotN
  float VdotNPow         = pow(VdotN, <power>);
  float VdotNcompPow     = pow(VdotNcomp, <power>);
  return (VdotN, VdotNcomp, VdotNPow, VdotNcompPow);
  ```

Fragment Shader: Skin Inputs

- VertexToFragment connector provides:
  - WorldEyeDirection
  - TangentToWorld Matrix
  - Blood Transmission Terms
- Fragment Shader texture inputs:

Normalization Cubemap	(Procedural, indexed by any vector)
Diffuse Lighting Cubemap	(HDRShop, indexed by normal)
Specular Lighting Cubemap	(HDRShop, indexed by reflection)
Hilight Lighting Cubemap	(Indexed by world eye direction)
Colormap/Specular	(Texcoord, rgb = color, a = “front” specular)
Bumpmap/Specular	(Texcoord, rgb = bump, a = “side” specular)
BloodColorMap	(Texcoord, rgb = blood color)
BloodTransmissionMap	(Texcoord)

r: blood pass-thru based on VdotN

g: blood pass-thru based on VdotNcomp

b: blood pass-thru based on VdotNpow

a: blood pass-thru based on VdotNcompPow

Fragment Shader: Skin Algorithm

- Like anything, diddle the knobs until i
- Our fairy shader ended up as:

```
worldNormal          = TangentToWorldMatrix * BumpMap

diffuseLight         = DiffuseLightCube(worldNormal)
specularLight        = SpecularLightCube(ComputeReflection(worldEyeDir
passThruLight        = HilightCube(worldEyeDir)

bloodAmount          = dot (BloodTransmissionMap, BloodTransmissionTe

diffuseColor         = lerp(ColorMap, BloodColorMap, bloodAmount)
specularColor        = lerp(frontSpecularMap, sideSpecularMap, BloodTransmissionVector.z)

return (occlusion*(diffuseLight *diffuseColor  + specularLight *specularColor + passThruLight))
```

Skin Simplification and Generalization

- **Diffuse, Specular, and Hilight can be computed**
- **Diffuse bump in tangent space was *heavy***
  - **9 move instructions in vertex shader**
  - **3 dot3's in fragment shader**
  - **Can do simpler bumpmapping in tangent space**
- **Blood term could just interpolate constant color**
- **Normalization cubemap optional (but cheap)**
- **Second specular map optional**
- **Hilight map optional**

Summary

- Blendshapes ar
  - Single multiply-a
  - Runs well in conj
  - Can improve 'squ
- Accumulated m
  - Unintuitive but ef
  - Faster on GPU o
- Skin Shaders ar
  - So is everything
  - Beautiful artwork
  - Dot(View,Surface

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Simon Green	Hair generation tool
Eugene D’Eon	Occlusion generation tool

Credits

- Art Team
  - Dan Burke, Bonnie O’Claire, Steven Gielser, Daniel Hornick
- Programming Team
  - Curtis Beeson, Joe Demers, Simon Green, Gary King, Hubert Nguyen, Thant Tessman
- Interns
  - Eugene D’Eon, Denis Dmitriev, Dean Lupini, Jonathan McGee, Alex Sakhartchouk
- Management
  - Mark Daly

Questions…

?