OpenGL & CUDA Tessellation

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Agenda

- OpenGL 4.x Tessellation
  - Motivation
  - OpenGL 4.x Tessellation Pipeline
  - Tessellation for terrain rendering
- Tessellating NURBS with CUDA

OpenGL 4.x Tessellation

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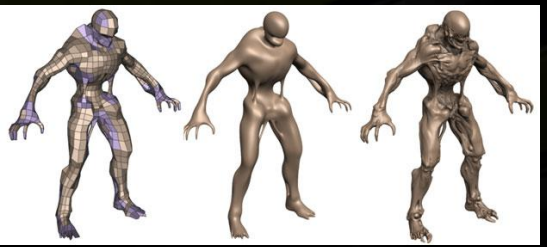
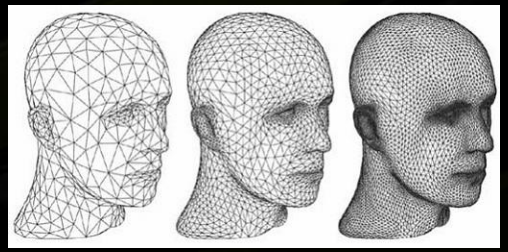
Motivation

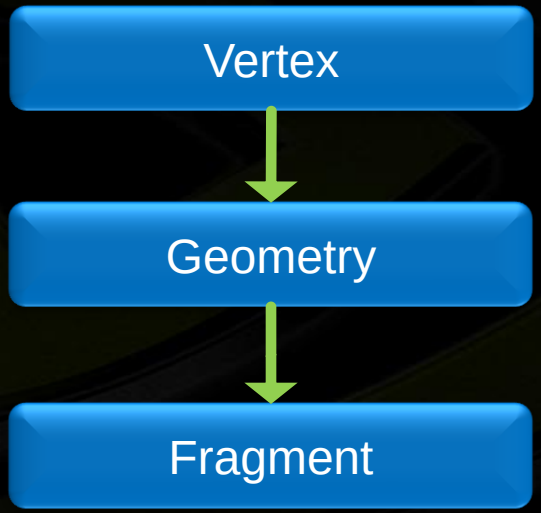
- Visual quality
- Memory Bandwidth
- Dynamic LOD
- Perform computations at lower frequency



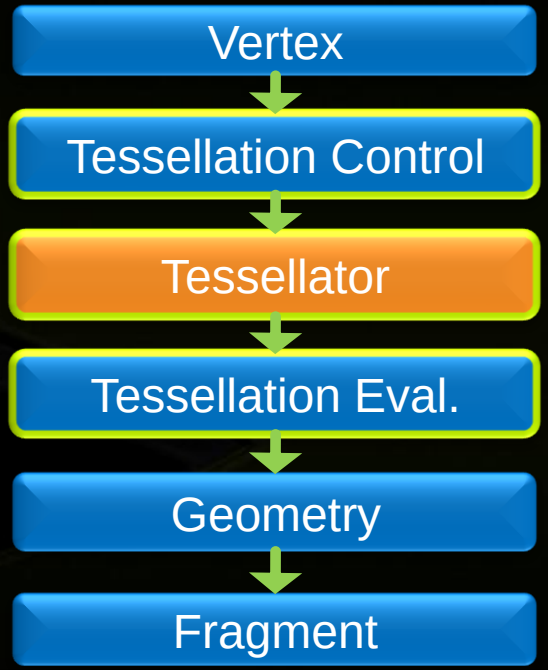


OpenGL pipeline: 3.x vs 4.x

- OpenGL 3.x



- OpenGL 4.x



OpenGL 4.x Pipeline

- 2 new Programmable stages
  - Tessellation Control Shader (GL_TESS_CONTROL_SHADER)
  - Tessellation Evaluation Shader (GL_TESS_EVALUATION_SHADER)
- 1 new Fixed function stage
  - tessellation primitive generator aka tessellator
- 1 new primitive type
  - Patches (GL_PATCHES)

Tessellation Control Shader

- Runs once for each vertex
- Computes LOD per patch
  - `gl_TessLevelOuter[4]`
  - `gl_TessLevelInner[2]`
- Optional
  - If not present tessellation level will be set to their default value
  - Default value can be changed using:
    - `glPatchParameterfv(GL_PATCH_DEFAULT_OUTER_LEVEL, outerLevels)`
    - `glPatchParameterfv(GL_PATCH_DEFAULT_INNER_LEVEL, innerLevels)`

Tessellator

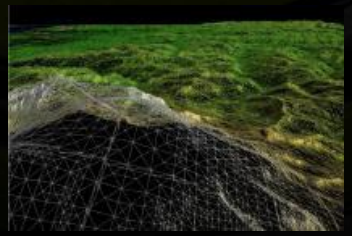
- Uses tessellation levels to decompose a patch into a new set of primitive
- Each vertex is assigned a (u, v) or (u, v, w) coordinate

Tessellation Evaluation Shader

- Compute the position of each vertex produced by the tessellator
- Control the tessellation pattern
- Can specify orientation of generated triangles
  - Counter-clockwise by default

Use case: Terrain Rendering

- Enhance terrain rendering algorithms
  - Chunked LOD
  - Geomipmapping
  - Persistent Grid Mapping




Tessellation heuristics

- Distance adaptive tessellation
  - Use the TCS to determine the edge tessellation level based on the distance to the viewpoint
- Orientation adaptive tessellation
  - Compute the dot product of the average patch normal with the eye vector (can be done offline, using CUDA)
- Screenspace adaptive tessellation
  - Compute edge midpoint screen space error metric
  - Use edge bounding sphere for rotation invariant heuristic

Performance considerations

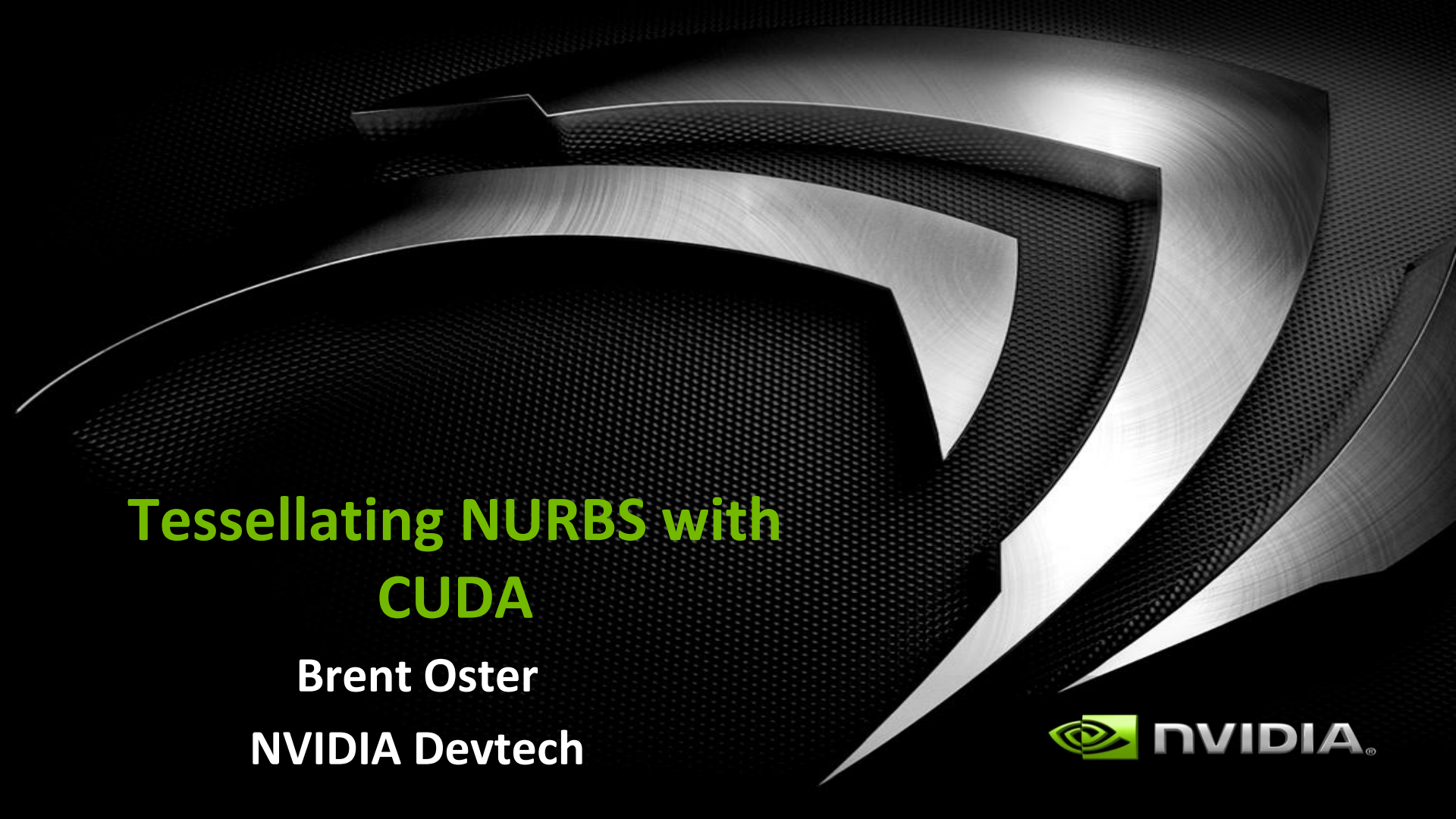
- Tessellation pipeline is not free !
- Avoid running tessellation shaders when not necessary
  - “Cache” tessellation results using Transform Feedback
  - Don’t forget to switch to GL_TRIANGLES when disabling tessellation

Performance considerations (cont'd)

- Consider using the Tessellation Control Shader to Cull patches not in frustum
  - `gl_TessLevelOuter[x] = 0`
  - Don't forget to take displacement into consideration
- Don't render occluded patches
  - Use occlusion queries

Summary

- OpenGL tessellation pipeline can greatly enhance the visual quality of your application
- Can adapt to existing rendering pipelines
- Implement efficiently
- Terrain Rendering is a straightforward candidate


Tessellating NURBS with CUDA
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NURBS

- Non-Uniform Rational B-Splines
- Curved surfaces commonly used in DCC / CAD modeling
- Points on surface defined by basis functions, CVs, weights

$$S(u,v) = \frac{\sum_{i=0}^{p}\sum_{j=0}^{q} B_{i,m}(u).B_{j,n}(v).P_{i,j}.w_{i,j}}{\sum_{i=0}^{p}\sum_{j=0}^{q} B_{i,m}(u).B_{j,n}(v).w_{i,j}}$$

- NURBS Basis $B_{i,k}$ defined recursively in terms of knot vector t_i

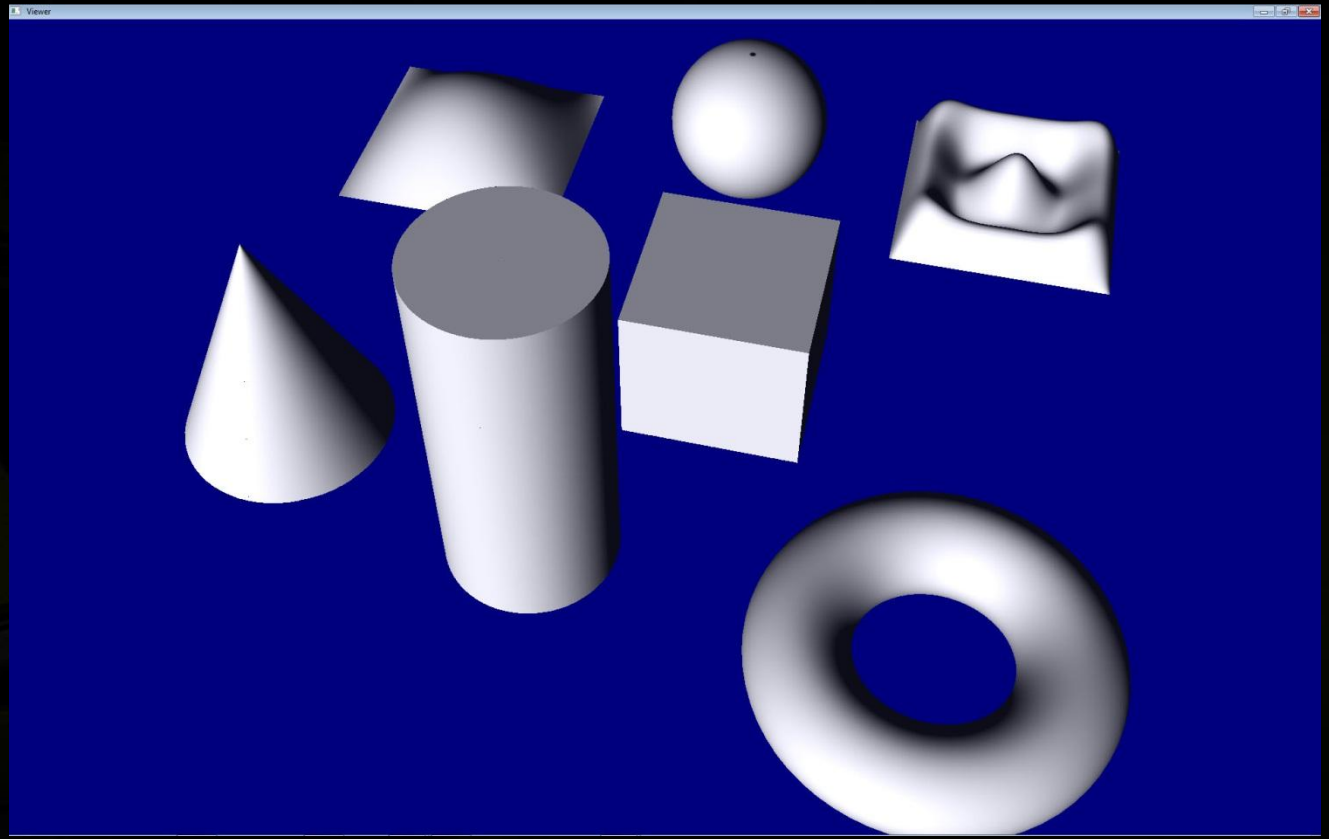
$$B_{i,0}(t) = \begin{cases} 1 \; if \; t_i \le t < t_{i+1} \\ 0 \; else \end{cases}$$

$$\forall k > 0, B_{i,k}(t) = \frac{t - t_i}{t_{i+k} - t_i} B_{i,k-1}(t) + \frac{t_{i+k+1} - t}{t_{i+k+1} - t_{i+1}} B_{i+1,k-1}(t)$$

Tessellating NURBS with CUDA

- Efficient direct tessellation of NURBS surfaces
- Arbitrary order per surface
- Arbitrary knot vectors & number of patches
- Programmable UV tessellation patterns
- Programmable triangulation
- Enable trimmed surfaces (TBD)
- Write Pos, Norm, Indices to OpenGL VBO
- VBO can then be used for multiple purposes

Directly Tessellating NURBS Surfaces



Tessellating NURBS Surfaces

CUDA Tessellation

- Input is an array of NURBS surfaces in device mem
  - Surface: CV's, UV knots, UV degree, boundary cond, …
- One NURBS surface handled per CUDA block
  - 1) Compute tessellation levels (separate kernel)
  - 2) Pre-compute polynomial coefficients on knot spans
  - 3) Compute custom (u,v) coordinates per vertex
  - 4) Compute vertex position, normal at each (u,v)
  - 5) Index through all quads, compute triangle indices

1) Compute Tessellation Levels

- Use CUDA Kernel to compute edge tessellation levels
- Simple formula for this demo
  - tessLevel = C*(Σ length(CP[i+1] – CP[i])) / distanceToCamera
  - i = 0 to (#CPs on edge)-1
  - C is user-defined constant
- Generates relatively constant triangle size on screen
- All vertices for all patches tessellated into one large VBO
- Must also compute unique pointers into VBO per patch
  - vertexIndex = atomicAdd(nTotalVertices, nVertsInSurface)
  - patch->vertexVBOptr = VBOStart + vertexIndex*sizeof(float4)

2) Pre-Compute Basis Polynomial Coefficients

- NURBS basis functions expanded in polynomial series

$$B_{i,n}(t) = \sum_{k=0}^{n} C_{i,n,k}(t).t^k$$

- Pre-compute coefficients per knot span (independent of t)

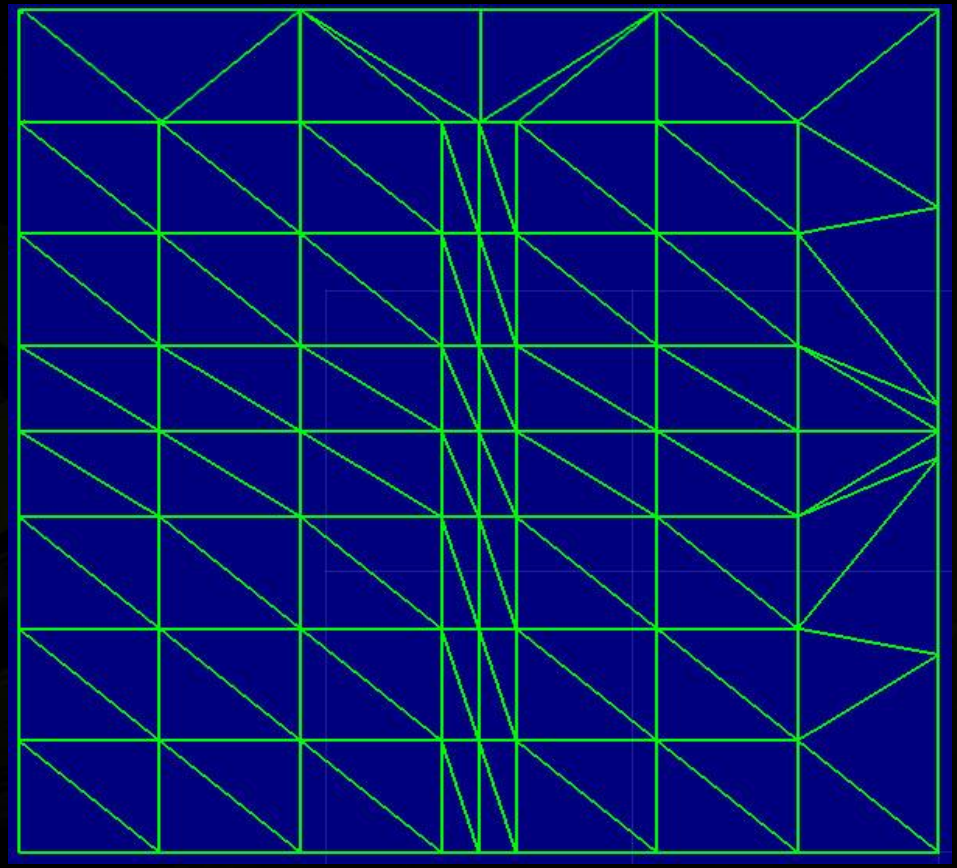
$$C_{i,0,0}(t) = B_{i,0}(t)$$

$$C_{i,n,0}(t) = \frac{t_{i+n+1}}{t_{i+n+1} - t_{i+1}} C_{i+1,n-1,0}(t) - \frac{t_i}{t_{i+n} - t_i} C_{i,n-1,0}(t)$$

$$C_{i,n,n}(t) = \frac{1}{t_{i+n} - t_i} C_{i,n-1,n-1}(t) - \frac{1}{t_{i+n+1} - t_{i+1}} C_{i+1,n-1,n-1}(t)$$

$$\forall k \in \{1..n-1\}, C_{i,n,k}(t) = \frac{C_{i,n-1,k-1}(t) - t_i.C_{i,n-1,k}(t)}{t_{i+n} - t_i} - \frac{C_{i+1,n-1,k-1}(t) - t_{i+n+1}.C_{i+1,n-1,k}(t)}{t_{i+n+1} - t_{i+1}}$$

3) Fractional, Symmetric U,V Tessellation



3) Compute U,V Tessellation Pattern

- Loop over all verts, increment i by blockDim.x

```
idx = i + threadIdx.x;
idxU = idx % nVertsU;
idxV = idx / nVertsU;
```

- Compute symmetric, fractional UV tessellation

```
u = u0 + (float)idxU*w;                          idxU < ceilTessU*0.5f - EPSILON
u = un - EPSILON - (ceilTessU - (float)idxU)*w;  idxU > ceilTessU*0.5f + EPSILON
u = u = u0 + 0.5f*(un - u0);                     otherwise
```

- For differing edge tess, make some vertices redundant:

```
idxU0 = (int)((ceil(edgeTess[0])/ceil(tessFactorU))*(float)idxU);
//compute u with idxU0 as above
```

4) Compute Vertex Positions and Normals

- Use pre-computed polynomial coefficients
- Compute vertex positions

$$S(u,v) = \frac{\sum_{i=0}^{p}\sum_{j=0}^{q} B_{i,m}(u).B_{j,n}(v).P_{i,j}.w_{i,j}}{\sum_{i=0}^{p}\sum_{j=0}^{q} B_{i,m}(u).B_{j,n}(v).w_{i,j}}$$

$$B_{i,n}(t) = \sum_{k=0}^{n} C_{i,n,k}(t).t^{k}$$

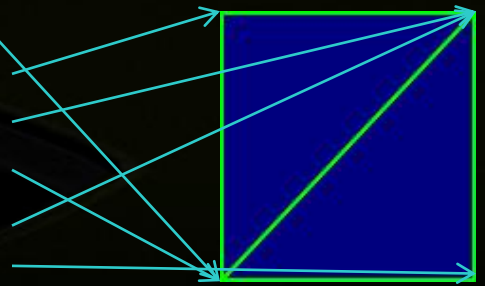
$$\frac{dB_{i,n}(t)}{dt} = \sum_{k=1}^{n} k.C_{i,n,k}(t).t^{k-1}$$

- Use Horner's rule to efficiently evaluate polynomials
- Compute U,V tangent vectors -> vertex normals
  - Use polynomial coefficients to compute derivatives

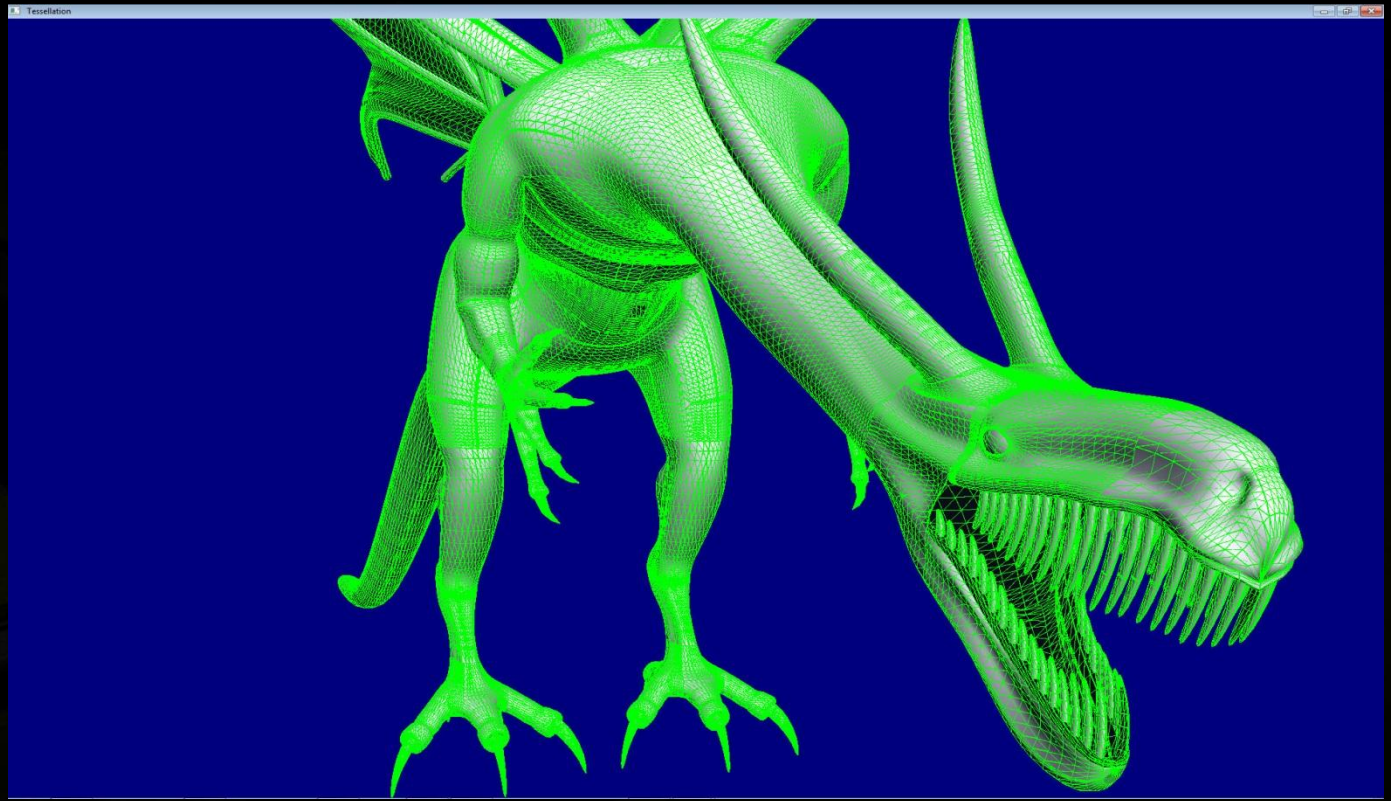
5) Compute Triangulation Indices

- Compute # of quads in surface
- Loop over all quads, increment i by blockIdx.x
- idx = I + threadIdx.x
- Compute idxU = idx % nQuadsU, idxV = idx / nQuadsU
- Compute indices for triangles

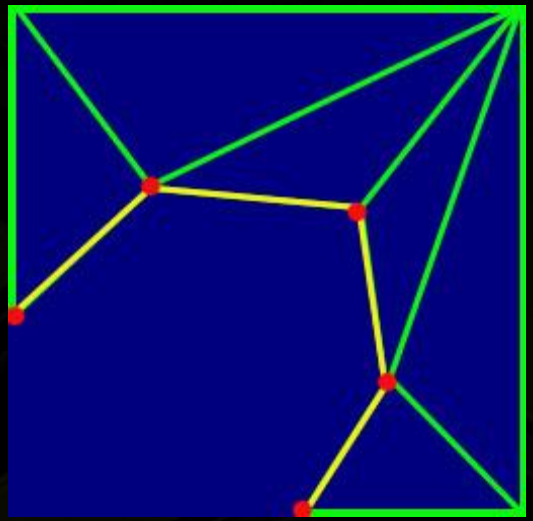
```
index[idx*6] = offset + idxU + idxV*nVerticesU;
index[idx*6+1] = offset + idxU + (idxV+1)*nVerticesU
index[idx*6+2] = offset + idxU+1 + (idxV+1)*nVerticesU;
index[idx*6+3] = offset + idxU + idxV*nVerticesU;
index[idx*6+4] = offset + idxU+1 + (idxV+1)*nVerticesU;
index[idx*6+5] = offset + idxU+1 + idxV*nVerticesU;
```



Results (438 surf, 3.6M tri in 36.4 ms)



Compute Triangulation Indices (Trimmed)



Questions?

- Feel free to contact us:
  - boster <at> nvidia <dot> com
  - prollin <at> nvidia <dot> com
- Samples will be posted after Siggraph

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