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Direct3D 11 Tessellation

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gameworks.nvidia.com


Image from Far Cry® 2, courtesy of Ubisoft

- **Pixels are meticulously shaded, but geometric detail is modest**

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Introduction(1)

- Provides cinematic visual details for real-time rendering
- Achieves more details with less storage
  - Input: a coarse mesh + displacement map
  - Geometry expansion on GPU
- Performs expensive computations at lower frequency

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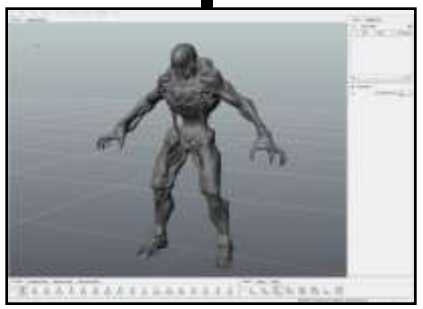
Introduction(2)

- Flexible Level of Detail (LOD) control
  - Adjusts LOD at run time
  - Creates geometry only where needed
  - Generates continuous level of detail
- Can be applied to almost everything that needs more details in a game scene
- Focus on character tessellation in this talk

Demos

Content Creation Pipeline

- Existing DCC tools: 3dsMax, Maya, Blender, Zbrush, Mudbox, Modo, Grazy Bump
  - Modeling Tools
  - Sculpting Tools
  - Baker Tools (generates displacement map, normal map, occlusion map, cavity map, etc)



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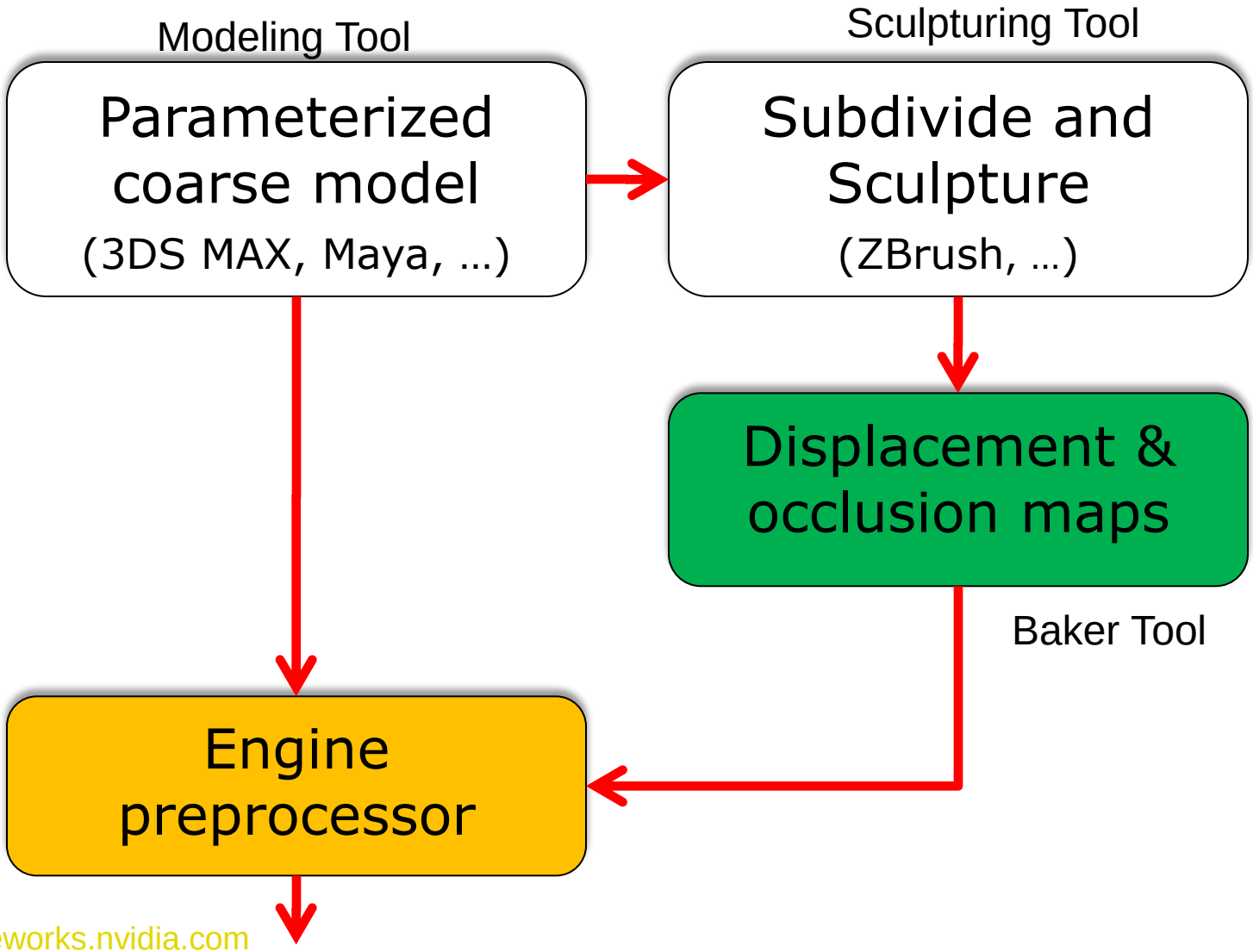
Content Creation Pipeline



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Overview of Various Tessellation Schemes

Tessellation Schemes

- Choose appropriate schemes for your art assets
  - Mesh connection type
  - Implementation complexity
  - Tradeoff between performance and visual quality
- Linear interpolation
- Local construction schemes
  - PN , Phong Tessellation
- Approximating Catmull-Clark Schemes

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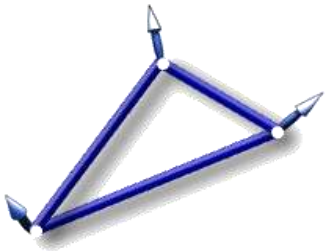
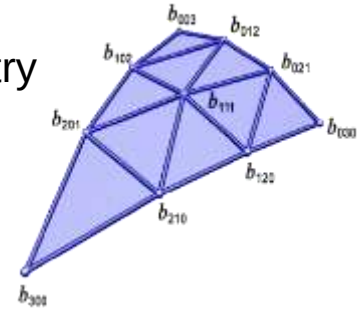
PN Triangles

- "**Curved PN Triangles**", by Alex Vlachos, Jörg Peters, Chas Boyd, and Jason Mitchell, I3D 2001.

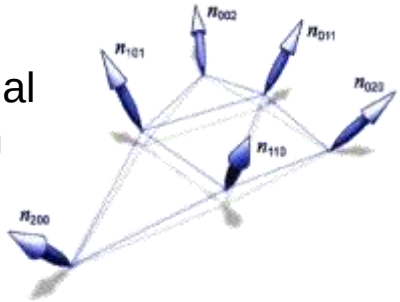


One input triangle

Geometry patch



Normal patch



- "**PN Quads**", by Jörg Peters, 2008.
  http://www.cise.ufl.edu/submit/files/file_020f70fe71888f602530143e2e326be2.pdf
  - The same formulae except for computing interior control points

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Phong Tessellation

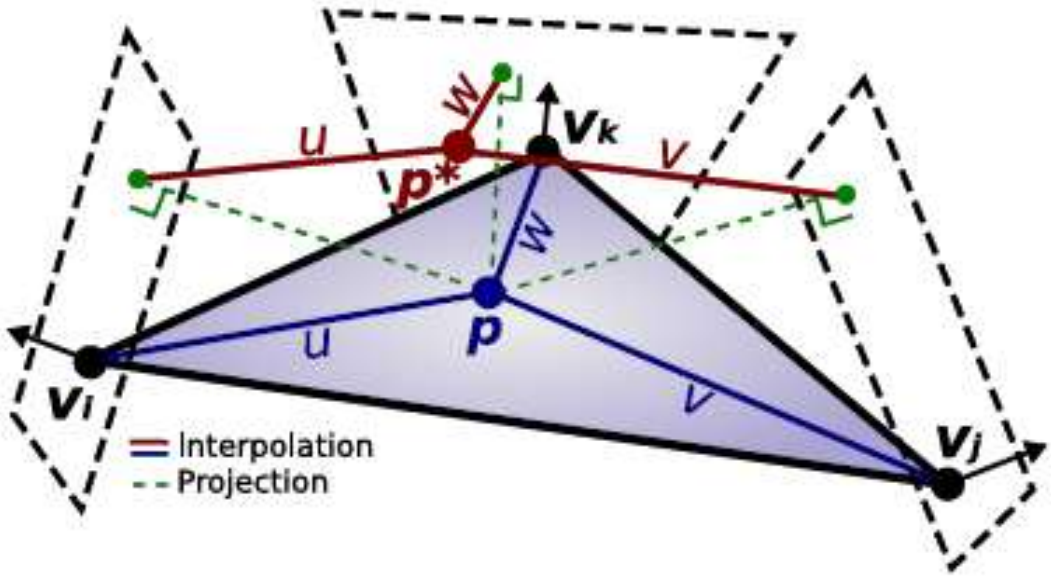

Figure 3: *Phong Tessellation principle. Instead of interpolating normals as in Phong Shading, we interpolate projection onto vertices tangent plane to define a curve geometry for each triangle.*

- From *Boubekeur and Alexa,* Siggraph Asia 2008

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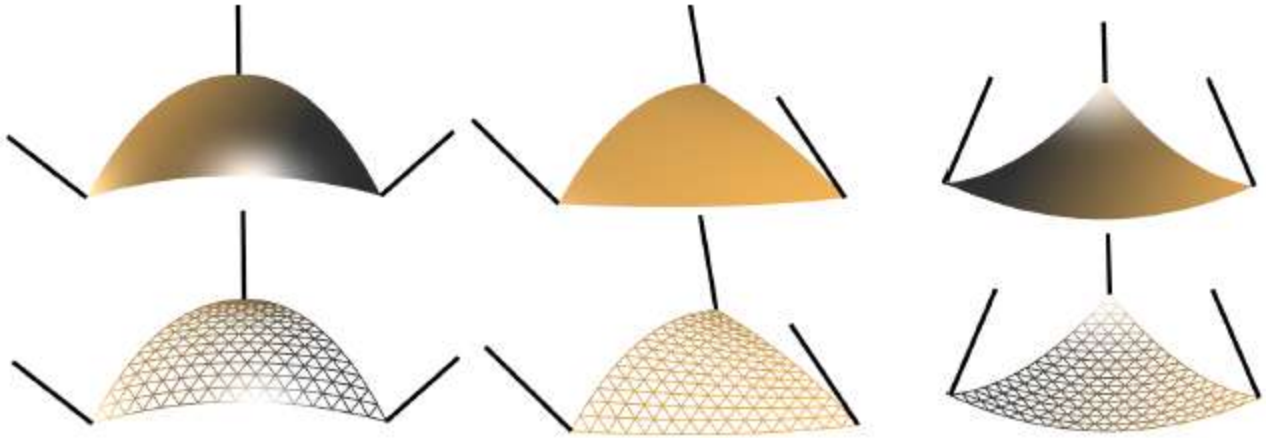
Phong Tessellation



Boubekeur and Alexa, 2008

- Simple scheme
- Does not handle inflections well
- Acceptable if initial subdivision is rather dense

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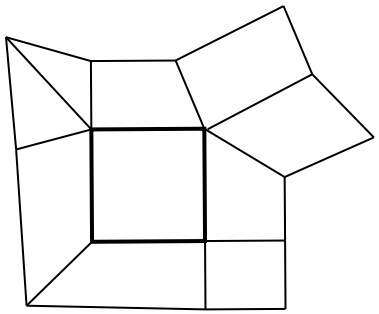
Approximating Catmull-Clark Subdivision Surfaces Schemes

- Provides movie-quality surfaces
  - Catmull-Clark subdivision surfaces are extensively used in movie production and modeling & sculpting tools
  - Suitable for quadrilateral meshes with few triangles in it



- Approximation rather than interpolation
- Requires the mesh info of a facet and its1-ring neighborhood

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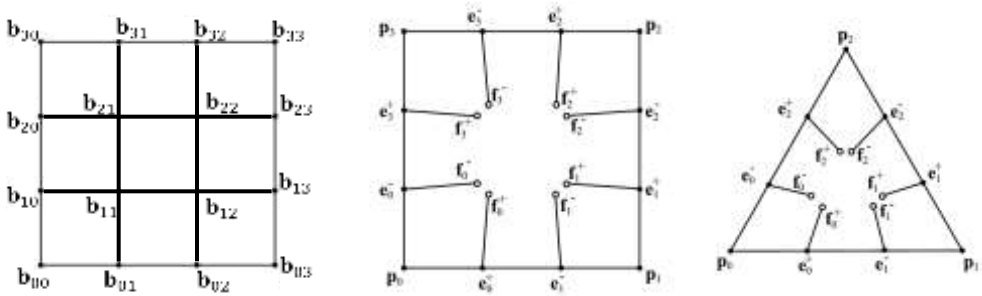
Approximating Catmull-Clark Subdivision Surfaces Schemes

- Convert each face of an input mesh to a gregory patch
  - Regular quad ➔ Bicubic Bézier Patch
  - Irregular quad ➔ Tensor-product
  - Triangle ➔ Triangular gregory patch



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Tessellation Schemes Comparison

	# of vertices in a patch primitive	# of control points	Base mesh	Surface fairness
Phong	3 Or 4	6 Or 9	▲ ■	Artifacts at inflection points and high curvature area
PN	3 Or 4	10+6 Or 16+9	▲ ■	Artifacts at high curvature area
Gregory ACC	16 to 32	15 Or 20	▲ ■	Similar to CC surfaces

- Various tessellation schemes differ at
  - Patch primitive
  - Control points computations (in Hull Shader)
  - Surface evaluation (in Domain Shade)

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DirectX 11

Direc3D11 Tessellation Pipeline

Patch Primitive

Input Mesh
(a collection of patch primitives)
Displacement Map
Normal Map (optional)

Input Assembler

Vertex Shader

Skinning

Hull Shader

Tessellator

Domain Shader

Setup/Raster

Pixel Sader

```
struct    VERTEX
{
    float3 vPosition        : POSITION;
    float2 vUV              : TEXCOORD0;
    float3 vTangent         : TANGENT;
    uint4  vBones           : BONES;
    float4 vWeights         : WEIGHTS;
};
```

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Direc3D11 Tessellation Pipeline

Patch Primitive

Input Mesh
(a collection of
patch primitives)

Input Assembler

Vertex Shader — **Skinning**

Hull Shader — **•Compute Control Points**
•Compute LOD

Tessellator — **Geometry expansion**

Domain Shader

Setup/Raster

Pixel Sader

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Direc3D11 Tessellation Pipeline

Patch Primitive

Input Mesh
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Input Assembler

Vertex Shader — **Skinning**

Hull Shader — **•Compute Control Points**
•Compute LOD

Tessellator — **Geometry expansion**

Patch Surface

Domain Shader — **•Surface Evaluation**
•Displacement mapping

Setup/Raster

Pixel Sader — **•Normal mapping (move to DS stage?)**
•Shading calculation

High-detailed Mesh

Practical Concerns

Tessellation Factors

- Domains: Triangle / Quad / Isolines
- Spacing:
  - Discrete / Continuous / Pow2
- Computed in the constant phase stage of the hull shader
  - Edge tessellation factors
  - Interior tessellation factors
    - ProcessTriTessFactorsMax
    - ProcessTriTessFactorsMin
    - ProcessTriTessFactorsAvg

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Avoid Unnecessary Geometry

- Camera distance
- Screen space
  - Be careful that edges are curved
  - Triangles under 8 pixels are not efficient
- Silhouette
  - Patches might be curved after tessellation
  - Displaced mapping makes silhouette detection harder
- Height values in Displacement Map

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Avoid Unnecessary Geometry

- Frustum culling and back face culling in the hull shader
  - Set all tessellation factors to 0
  - Culled patches will not send down to the pipeline
- Issues when back faces are detected
  - Patches might be curved after tessellation
  - Displaced mapping adds more variations for face orientations

Water-tight Tessellation

- Non-watertight position evaluation causes small cracks
- Non-watertight normal and tangent space evaluation causes shading discontinuity
- Causes
  - Limited floating point precision issue
  - Texture seams are discontinuities in the parameterization

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Floating Point Consistency

- FP addition is non commutative:
  - A + B + C + D != D + C + B + A
  - (A + B) + (C + D) == (D + C) + (B + A)
- FMA is not equivalent to MUL+ADD
  - A*a + B*b → FMA(A*a, B, b) != FMA(B*b, A, a)
- Use consistent or symmetric evaluation order along shared edges
  - Corner and edge control points computation
  - Surface evaluation

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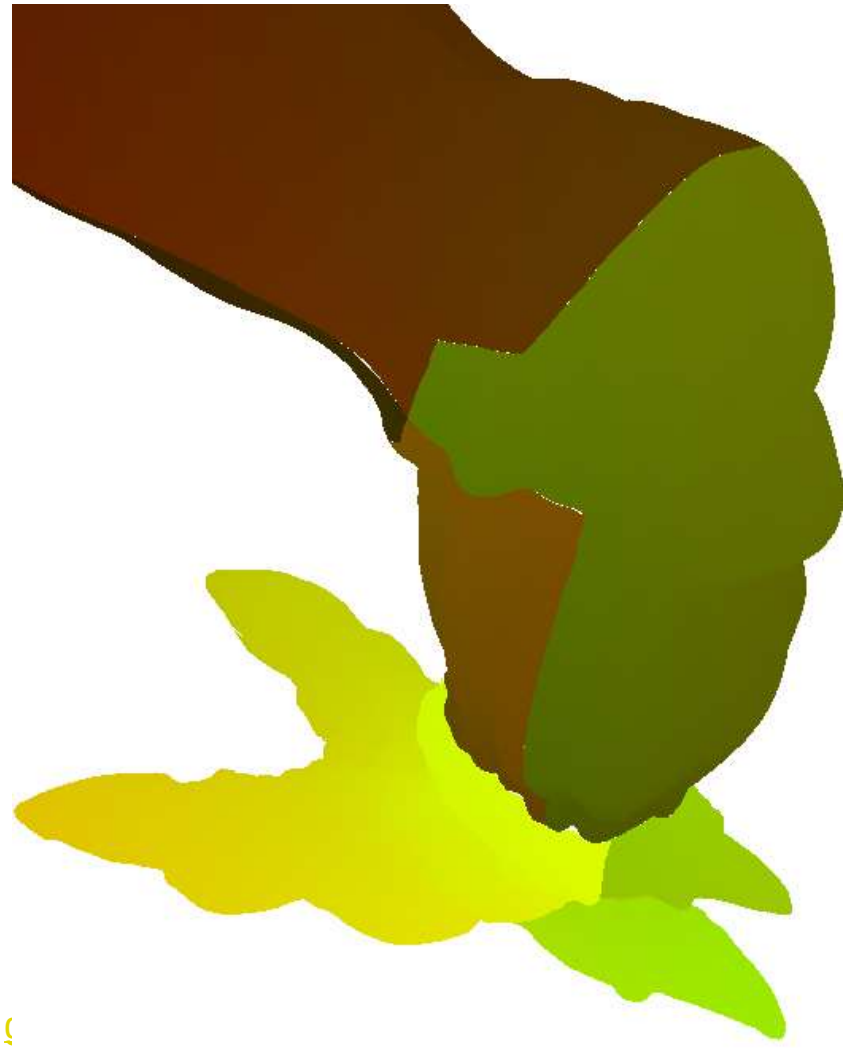
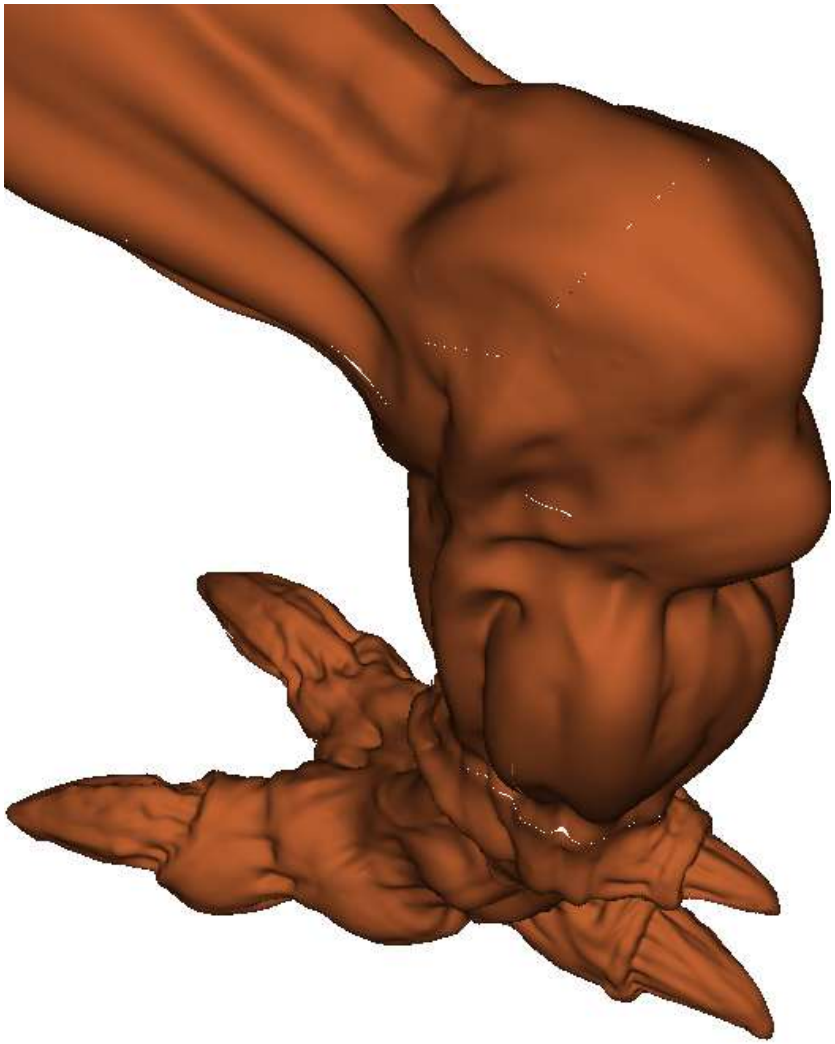
Cracks: Discontinuity in parametrization





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Solution for cracks

- Artist work
  - Hide texture seams
  - Kill displacement to zero on texture atlas seams
  - Remapping to unit length and orientation
- We suggested automatic ownership-based solution

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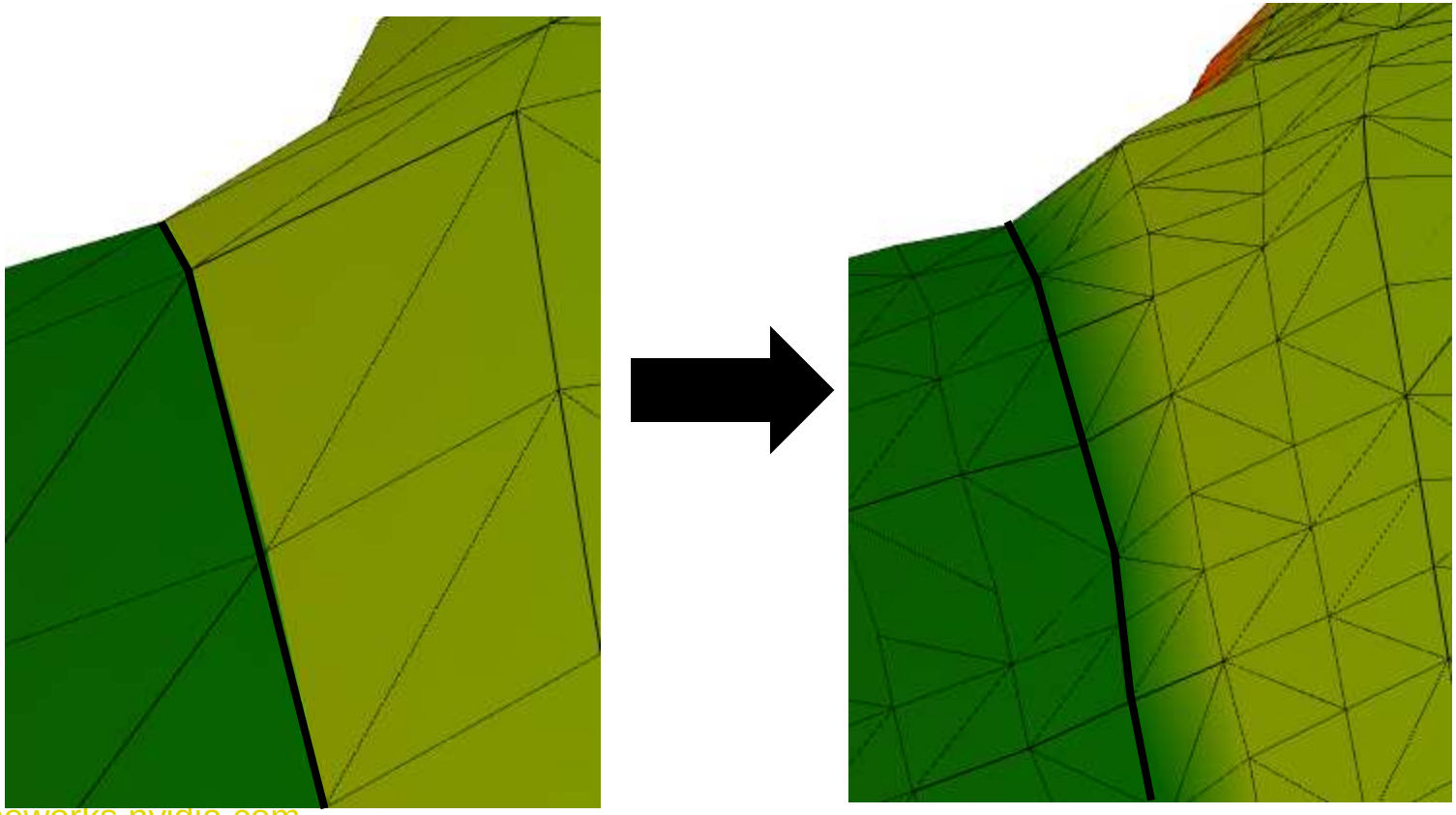
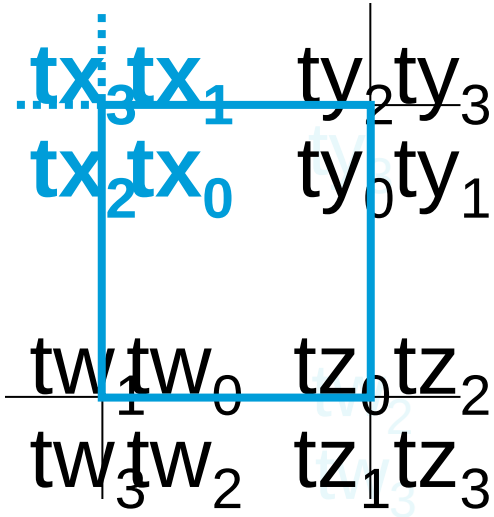
Cracks: Ownership-Based Solution

- Boundary triangles share the same texture coordinates data



Watertight Displacement

- Store 4 texture coordinates per vertex (0: interior, 1,2: edges, 3: corner)
  - 16 per quad patch, 12 per triangle patch
  - The corresponding texture coordinate can be selected using the value of the parametric coordinate UV
  - Compute Barycentric interpolation of texture coordinates



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Creases and Corners

[KMDZ09]

- Indicated in the input mesh where vertices that share the same position but have different normals
  - Solution 1: insert tiny polygons (triangles or quads) on creases/corners
    - Insertion by artists
    - Automatic detection and insertion
  - Solution 2: tag the vertices on creases/corners
    - Preprocessing step to add tags
    - Modify correspondent shader code

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Tessellation in Metro 2033

Metro 2033: the game

- A combination of horror, survival, RPG and shooting
- Based on a novel by Dmitry Glukhovsky

Tessellated Monster in Metro 2033

Use Phong tessellation

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From *Metro 2033*, © THQ and 4A Games

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More Metro Monsters…

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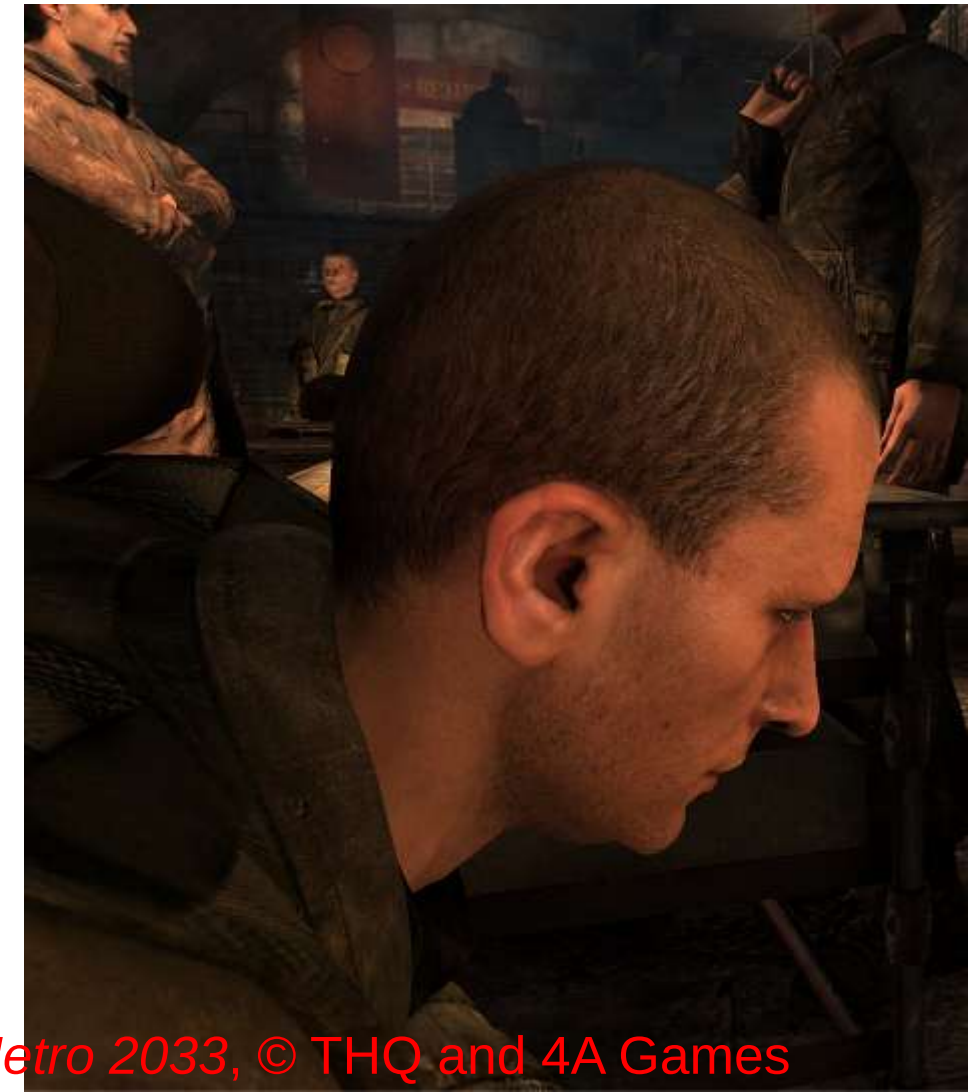
… and Characters



From *Metro 2033*, © THQ and 4A Games

… more Characters

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Start with a Coarse Base Mesh

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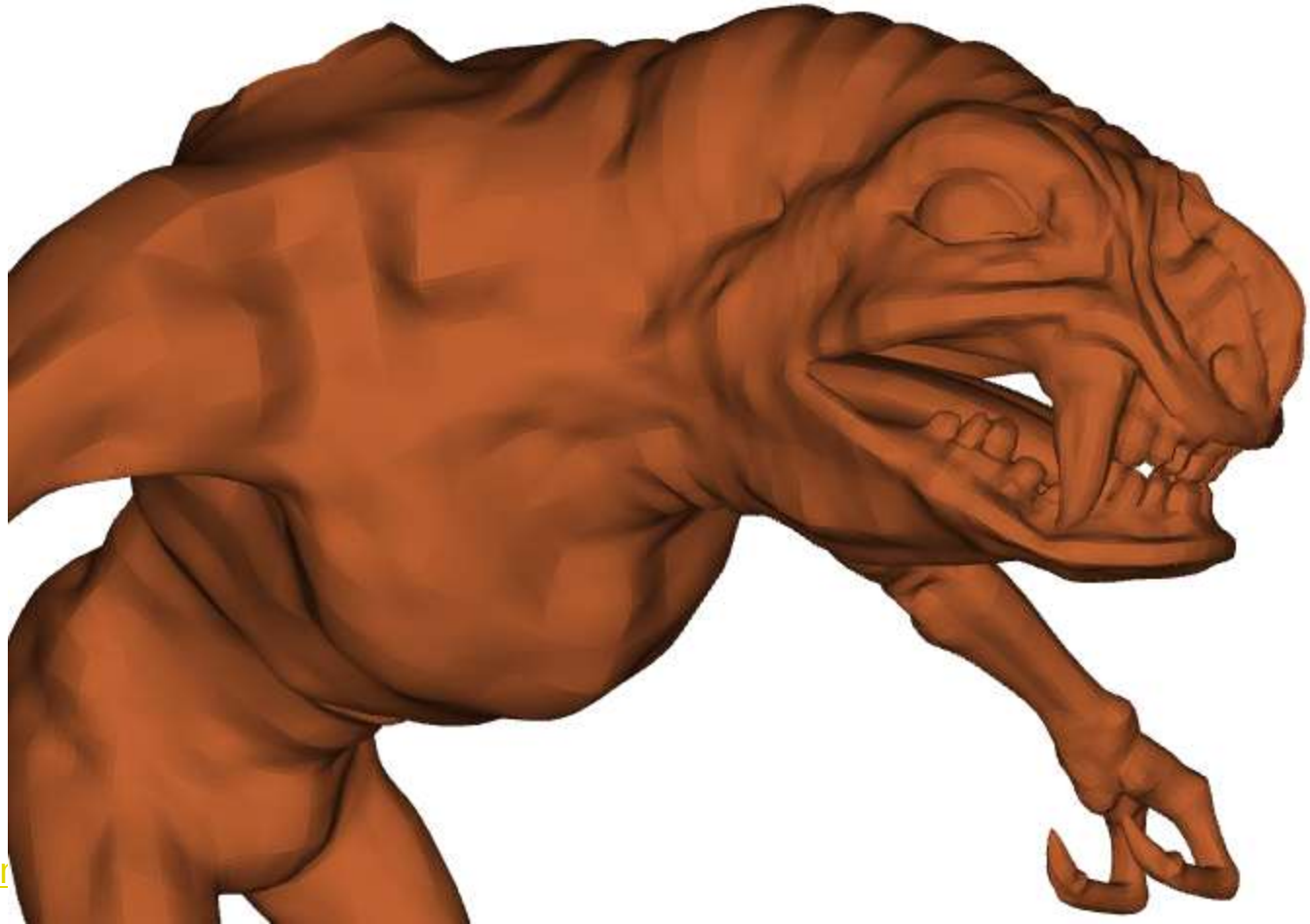
HW-based Subdivision



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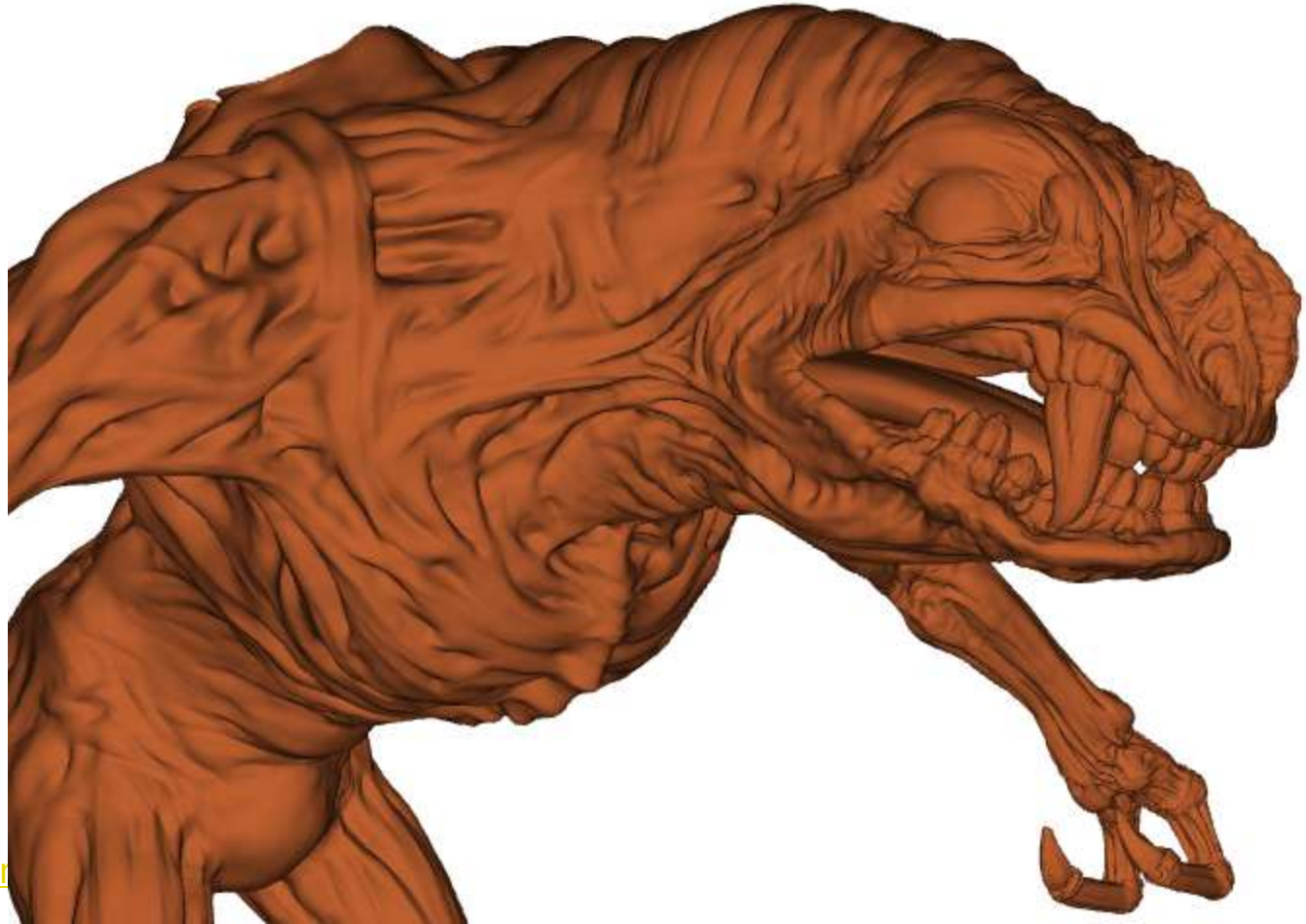
Apply Displacement



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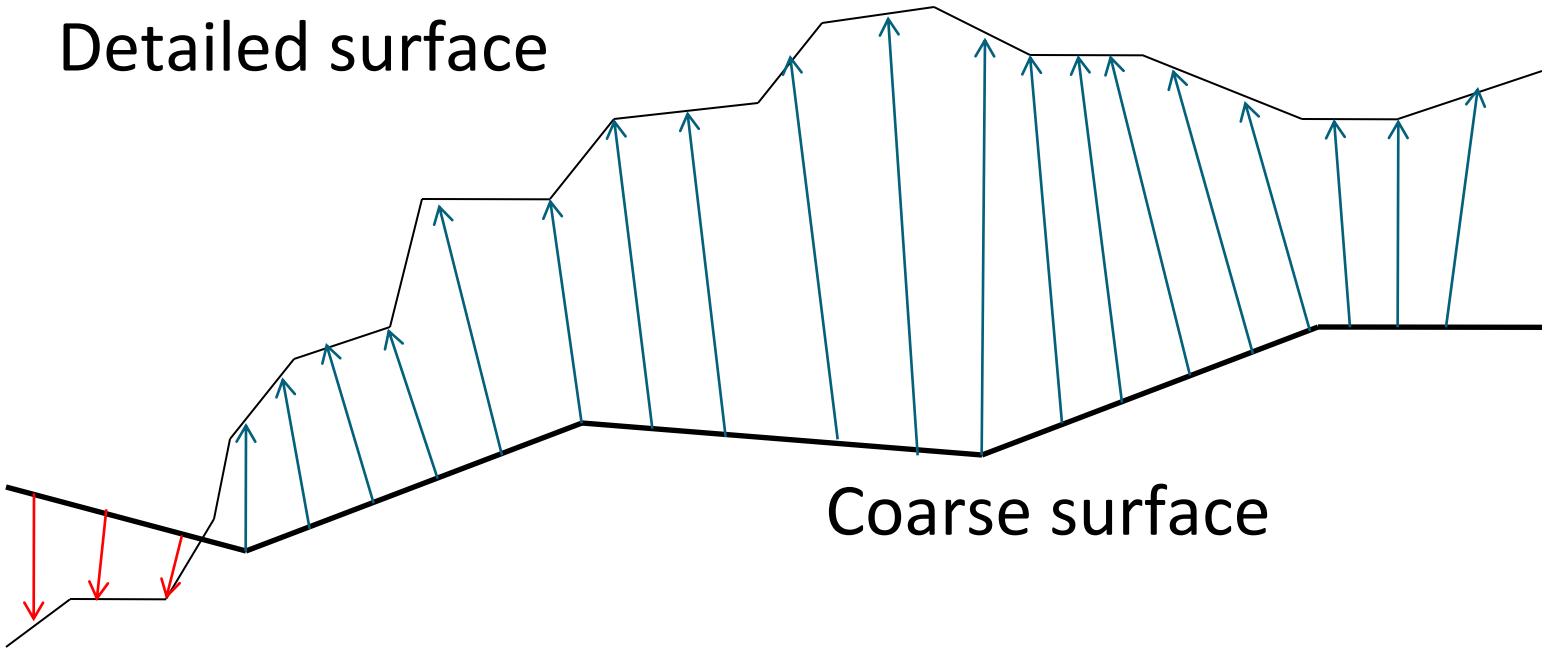
Computing Displacement

- Input: coarse and detailed model



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LOD Computation

- TESS_FACT = LEN * NP * Q / DIST
- Where LEN is edge length in world space
- NP is number of pixels on the screen
- Q is quality constant
- DIST is distance from observer to edge center

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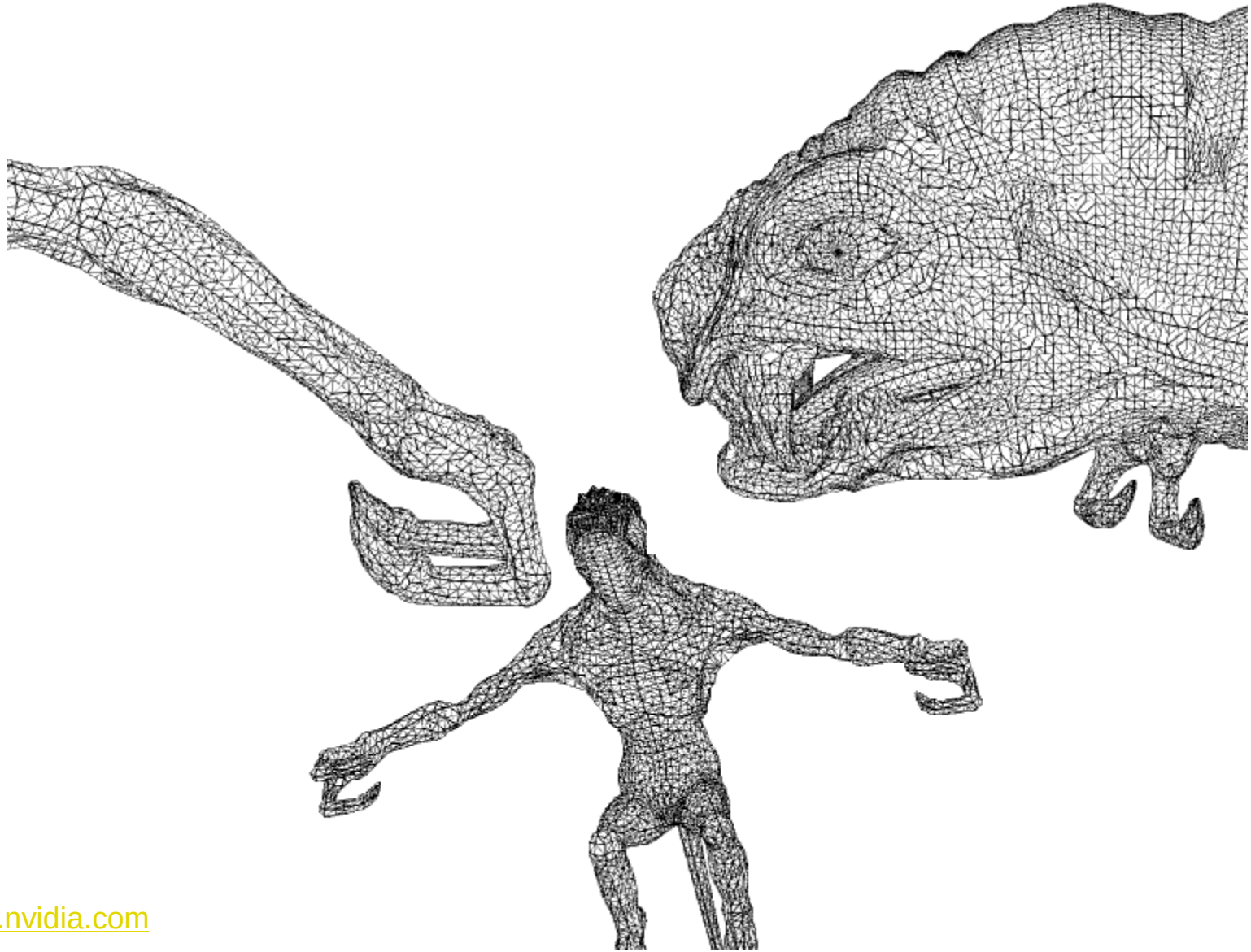
Constant Triangle Size



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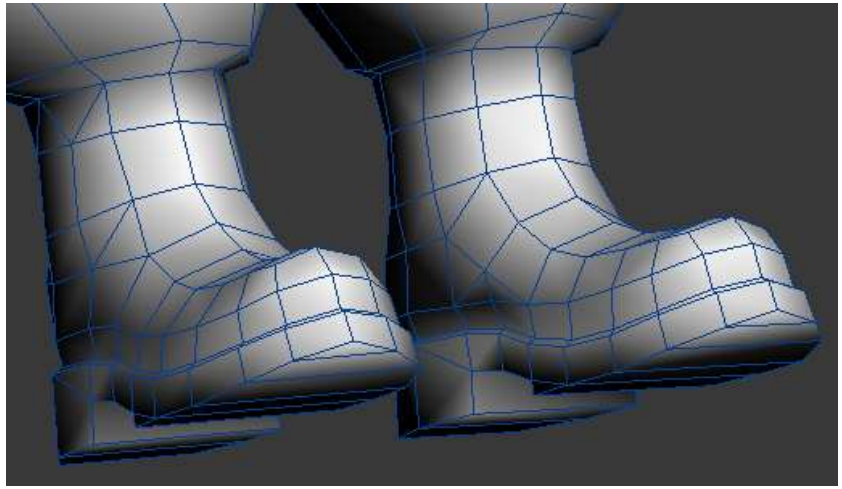
Artifacts on Hard Edges



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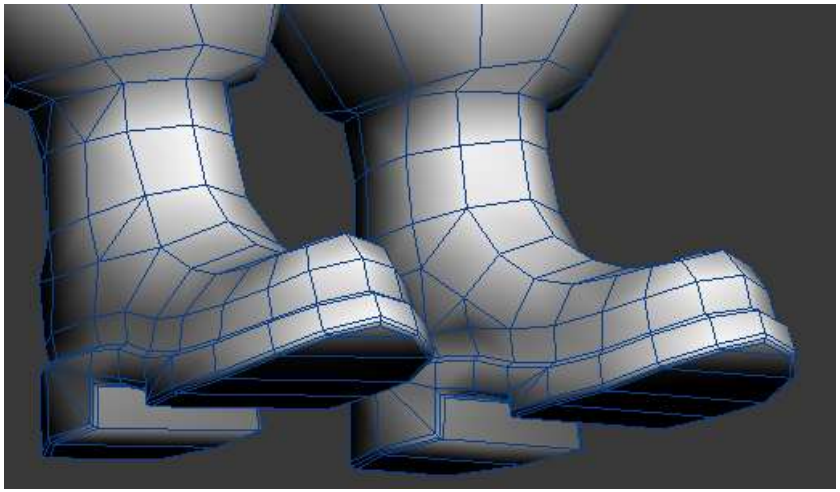
Transitional Polygons



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Summary

- Direct3D11 Tessellation enriches visual details with flexible LOD control
- Choose a tessellation scheme that fits your needs
- Implement it efficiently
- It’s time to bring games to the next level

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Thank you!

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