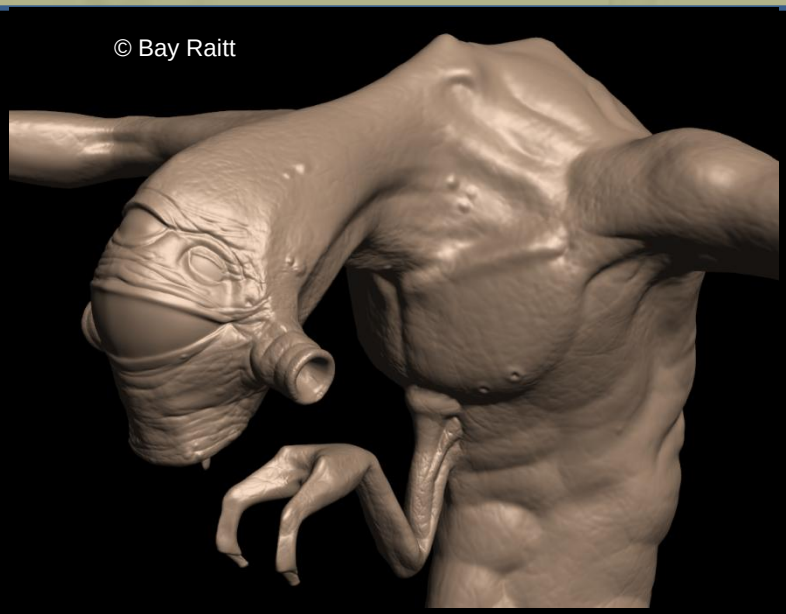
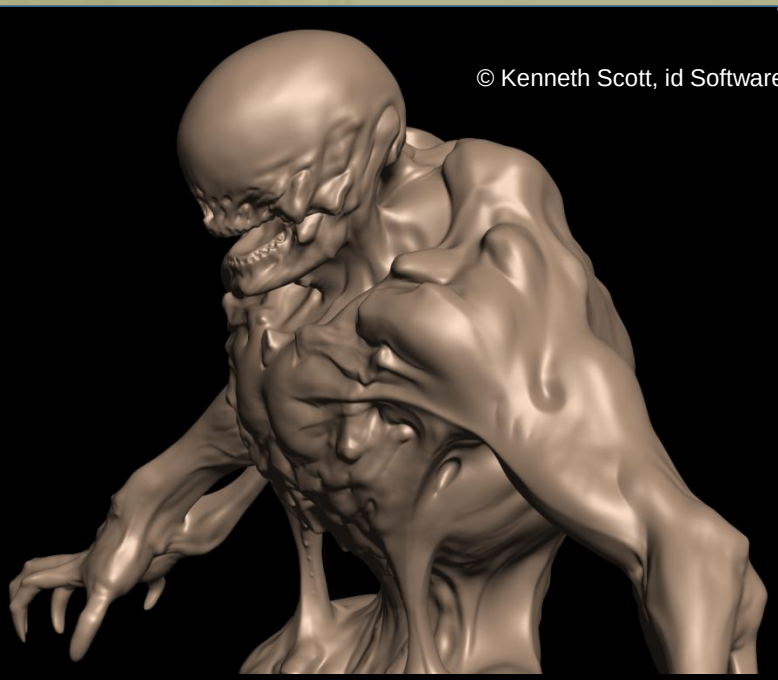
Implementation

Tianyun Ni

Overview

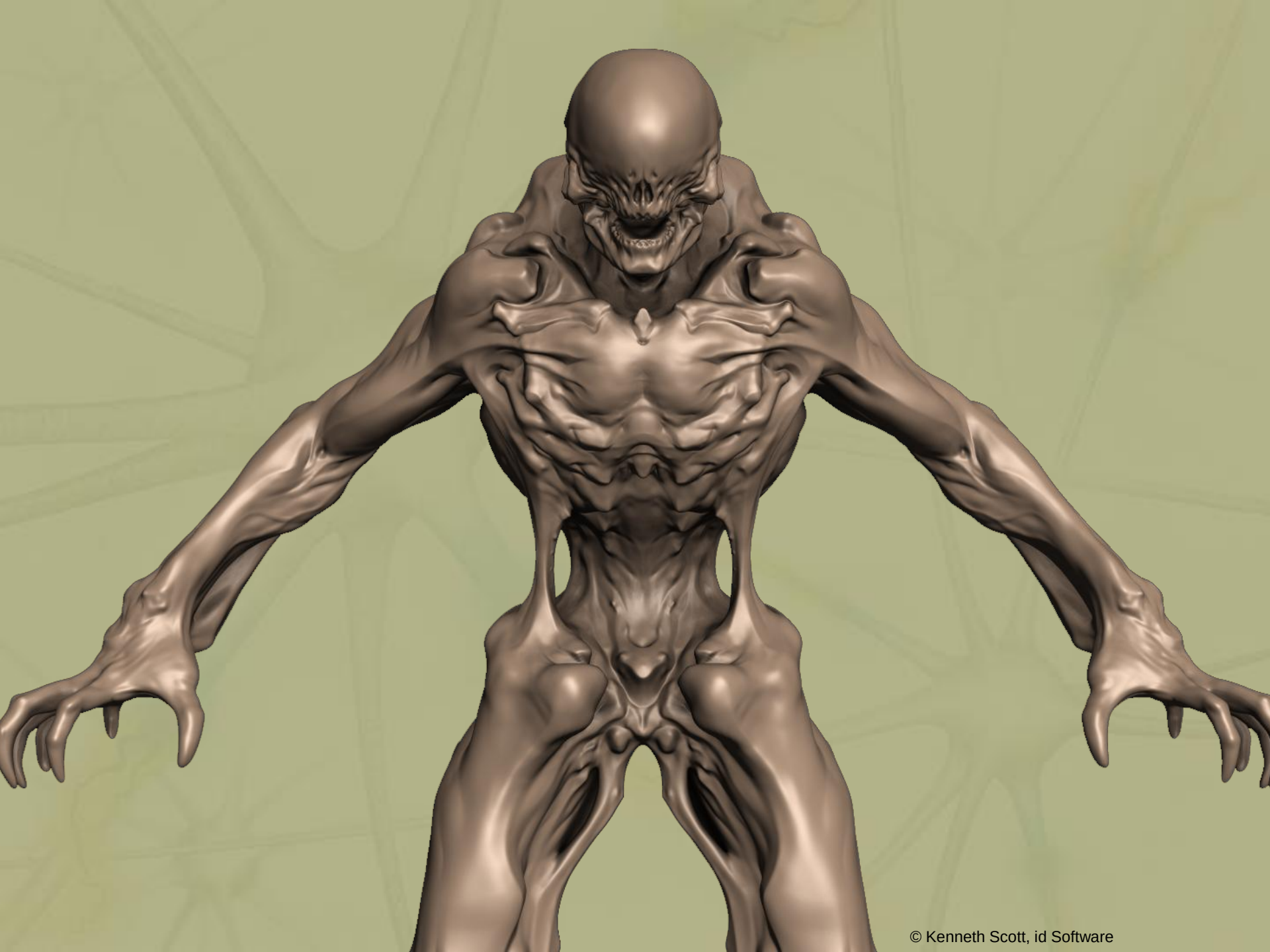
- This course section discusses real-time rendering of efficient substitutes for subdivision surfaces.
  - The advent of DirectX 11
  - Recent theoretical results
- Implementation on current hardware
- Practical implementation issues


© Bay Raitt

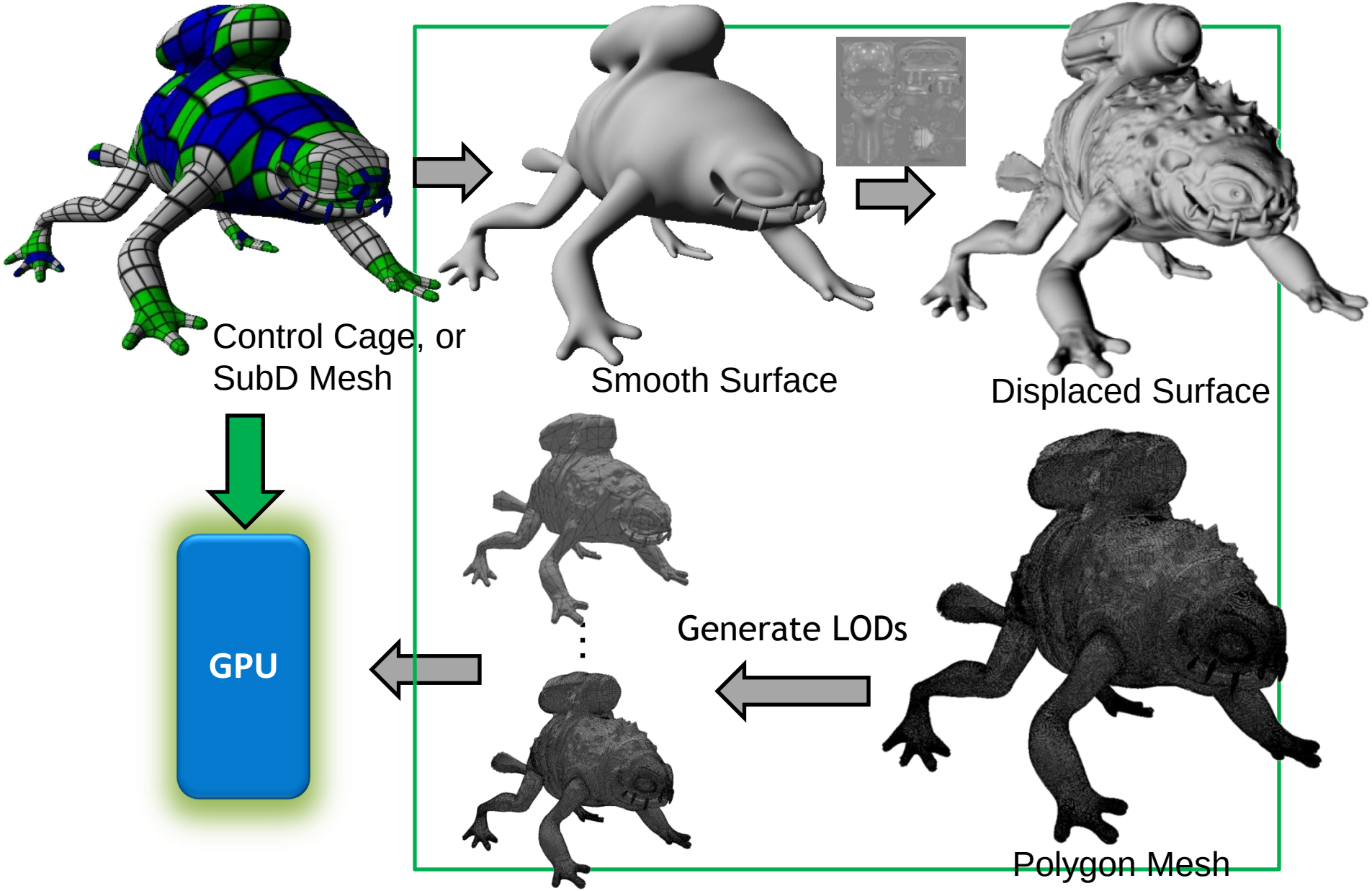

© Kenneth Scott, id Software


© Kenneth Scott, id Software

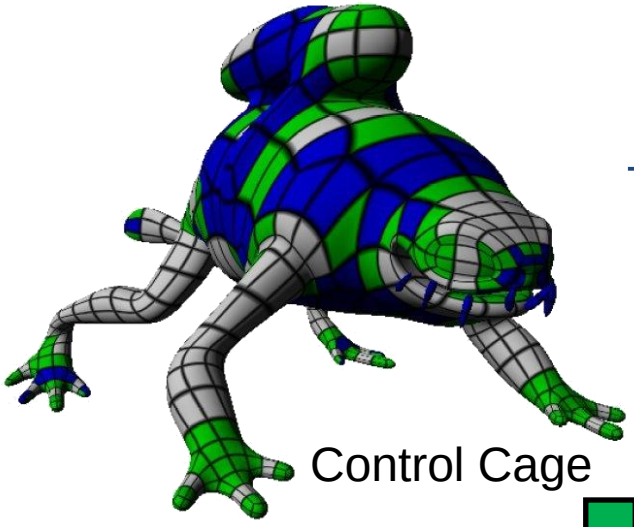

© Mike Asquith, Valve


© Kenneth Scott, id Software

Current Authoring Pipeline

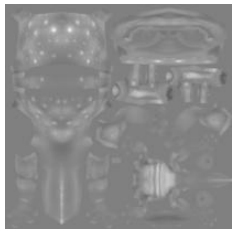


Direct3D 11 Pipeline For Real-time Tessellation Rendering



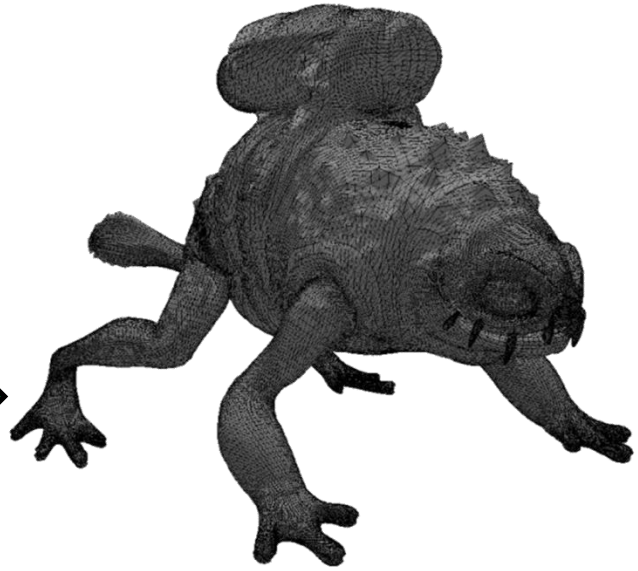
Control Cage

+



Displacement Map

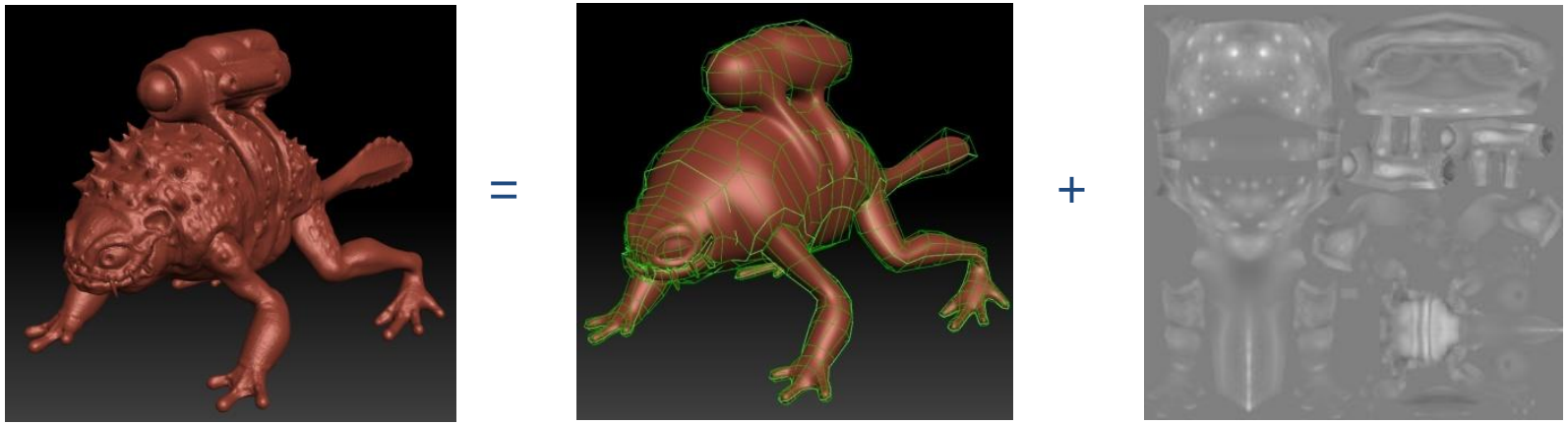
GPU



Optimally Tessellated Mesh

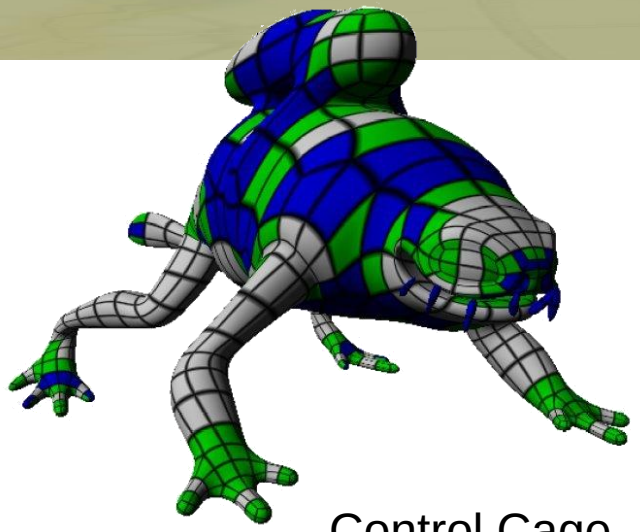
Direct3D 11 Tessellation Pipeline

- Save memory and bandwidth
  - Memory is the critical bottleneck to render highly detailed surfaces



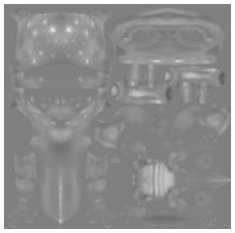
	Level 8	Level 16	Level 32	Level 64
Regular Triangle Mesh	16MB	59MB	236MB	943MB
D3D11 compact representation	1.9MB	7.5MB	30MB	118MB

Direct3D 11 Tessellation Pipeline



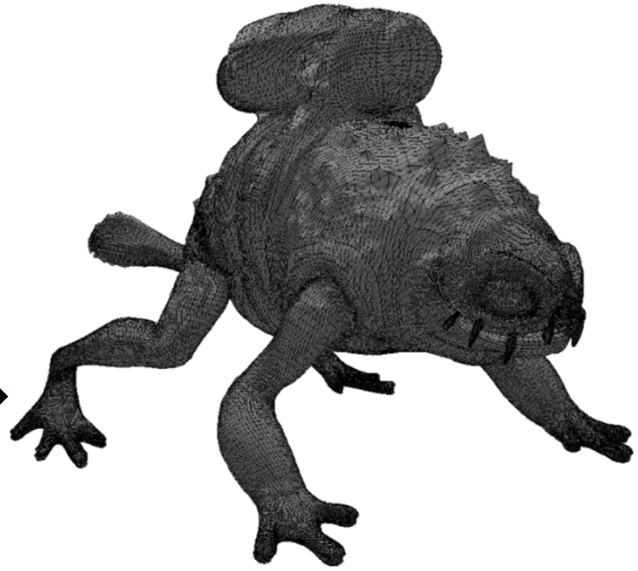
Control Cage

\+



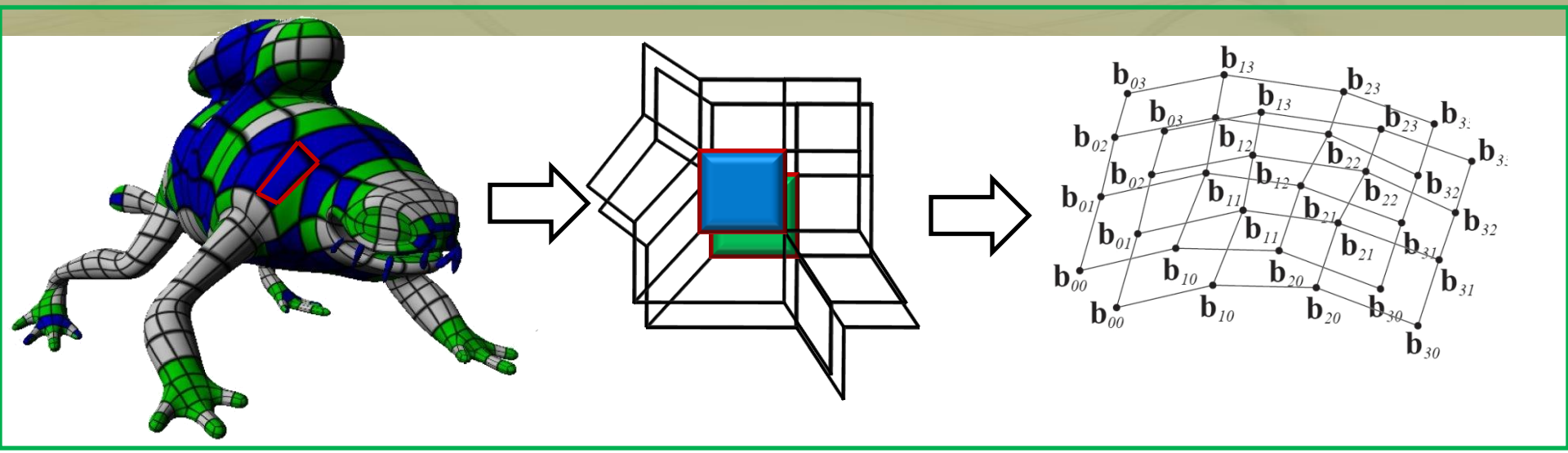
Displacement Map

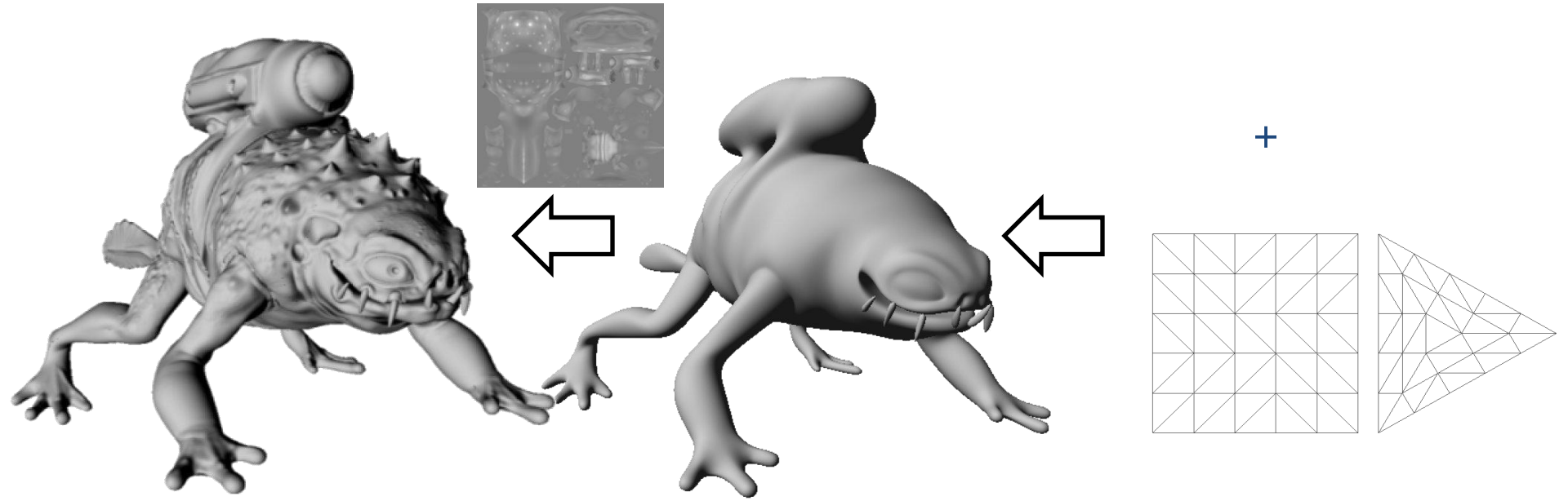
GPU



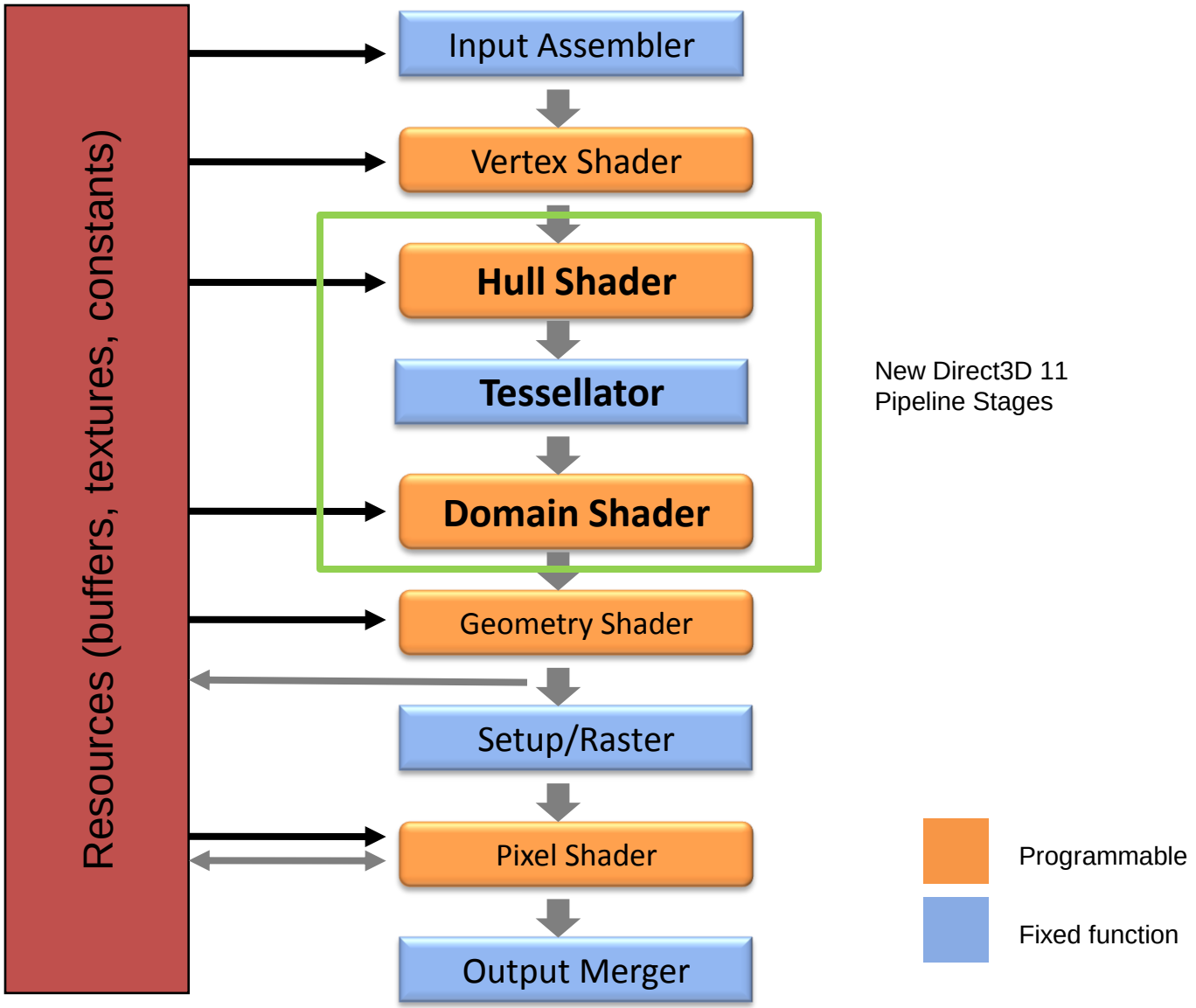
Optimally Tessellated Mesh

Tessellation Process



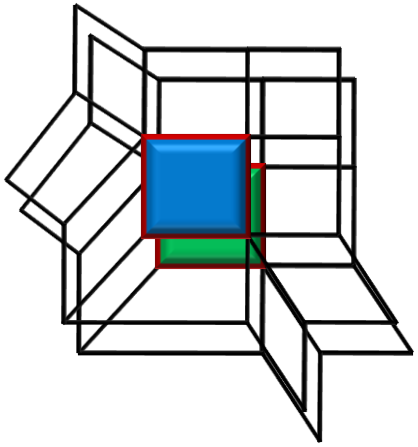


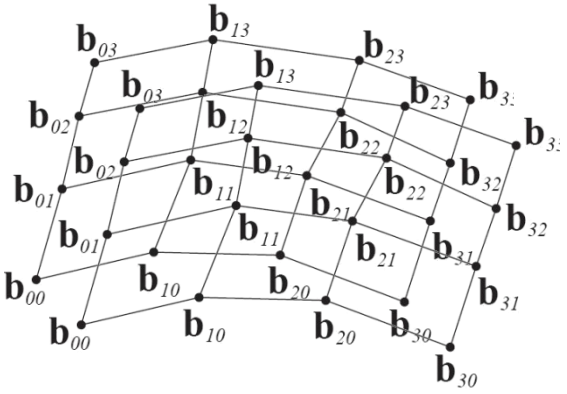
Direct3D 11 Graphics Rendering Pipeline

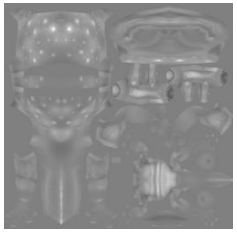


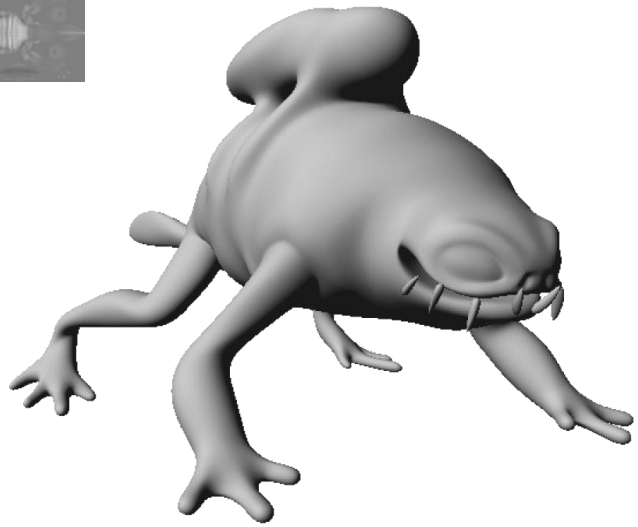
Direct3D 11 Tessellation

Vertex Shader

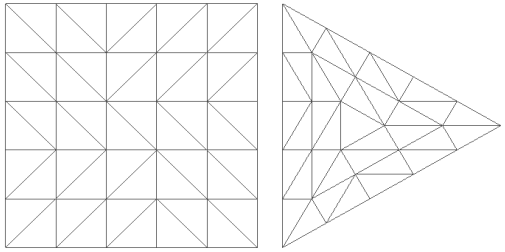






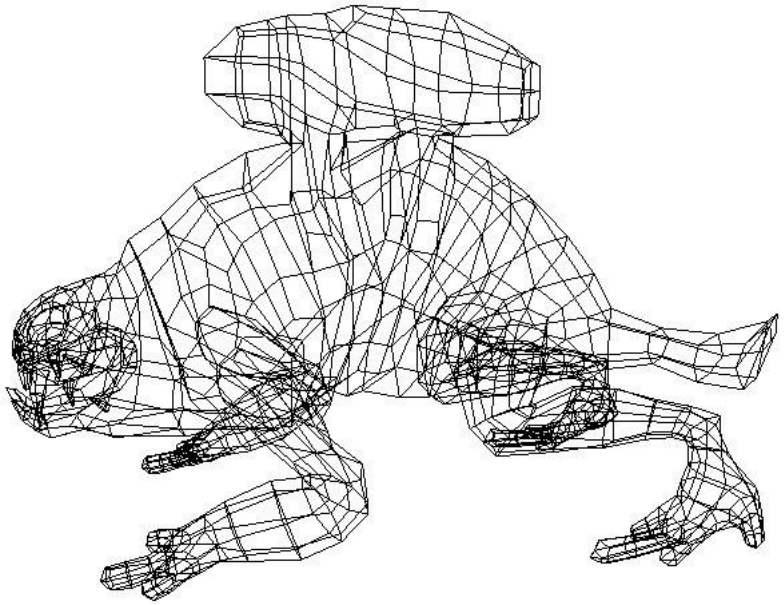


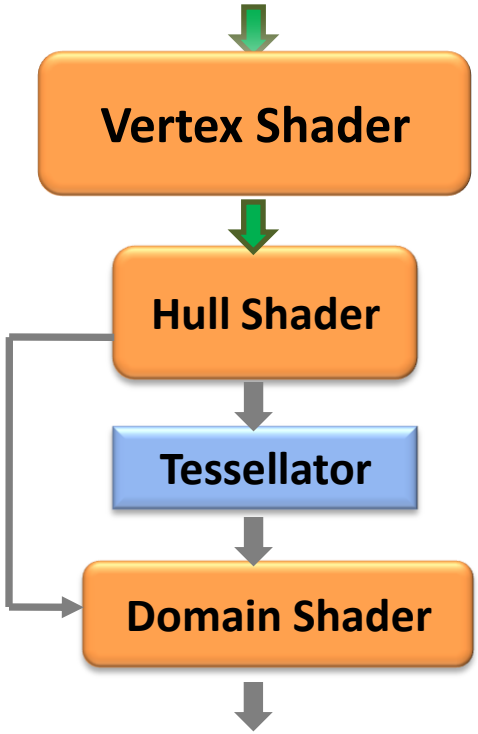
+



Vertex Shader

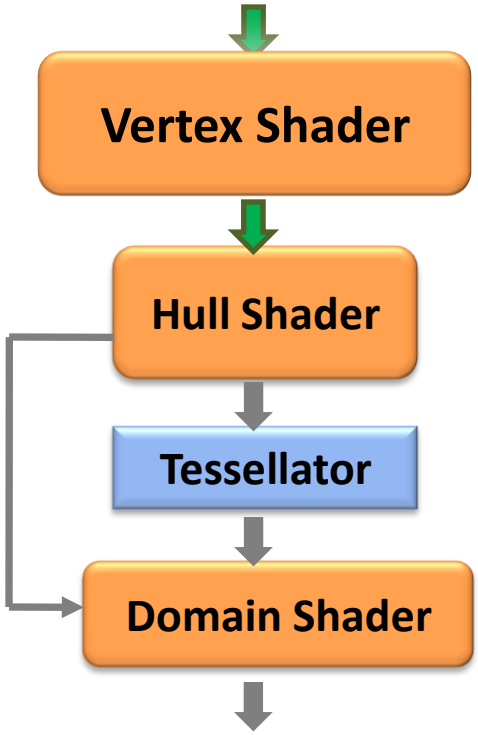
- Transforms control cage vertices





Vertex Shader

- Applications
  - Realistic animation: skinning, morph targets, etc



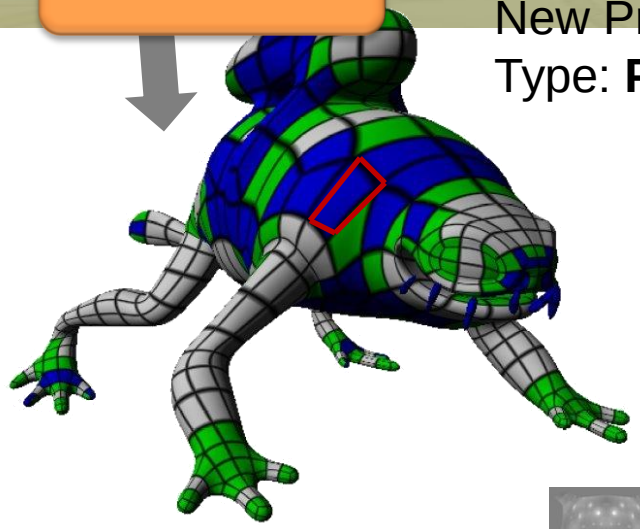
  - Physical Simulation: hair simulation, particle system, soft body deformation

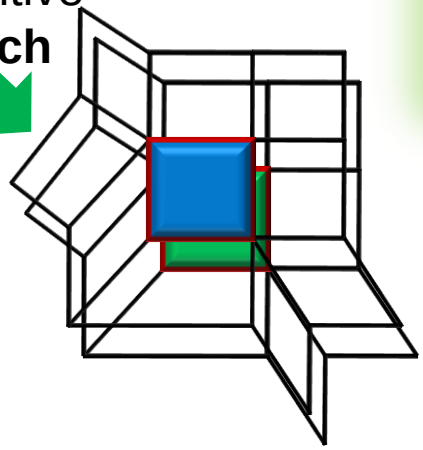
Direct3D 11 Tessellation

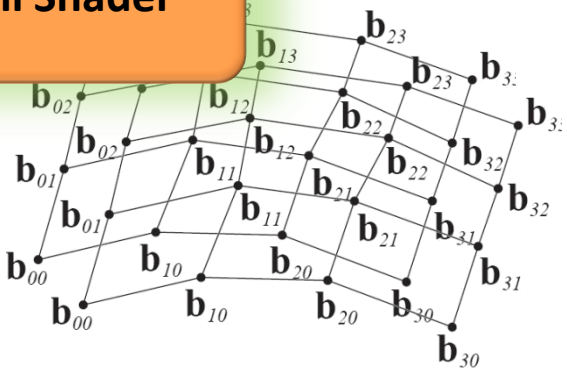
Vertex Shader

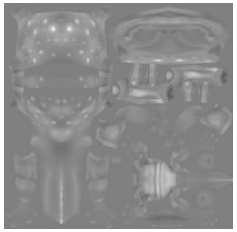
New Primitive
Type: **Patch**

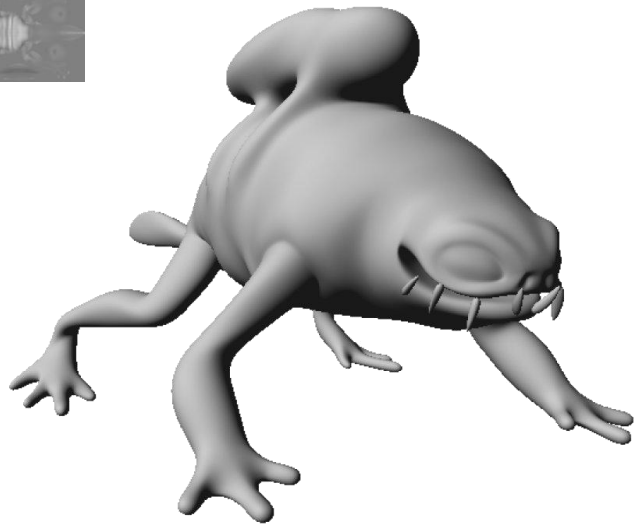
Hull Shader



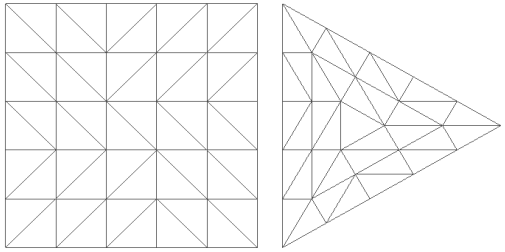






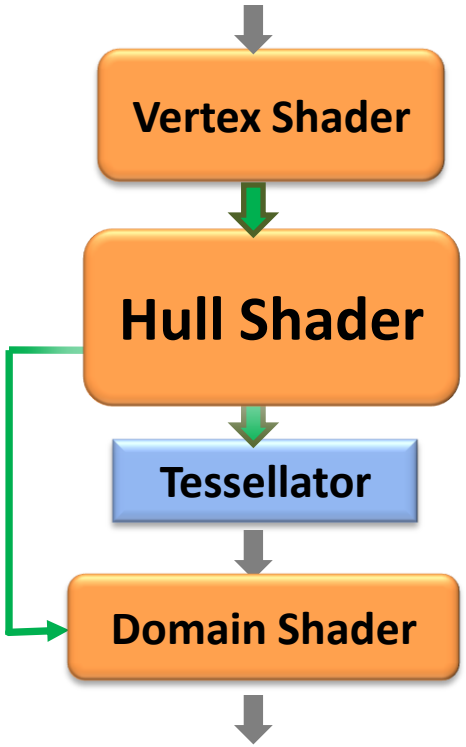


+



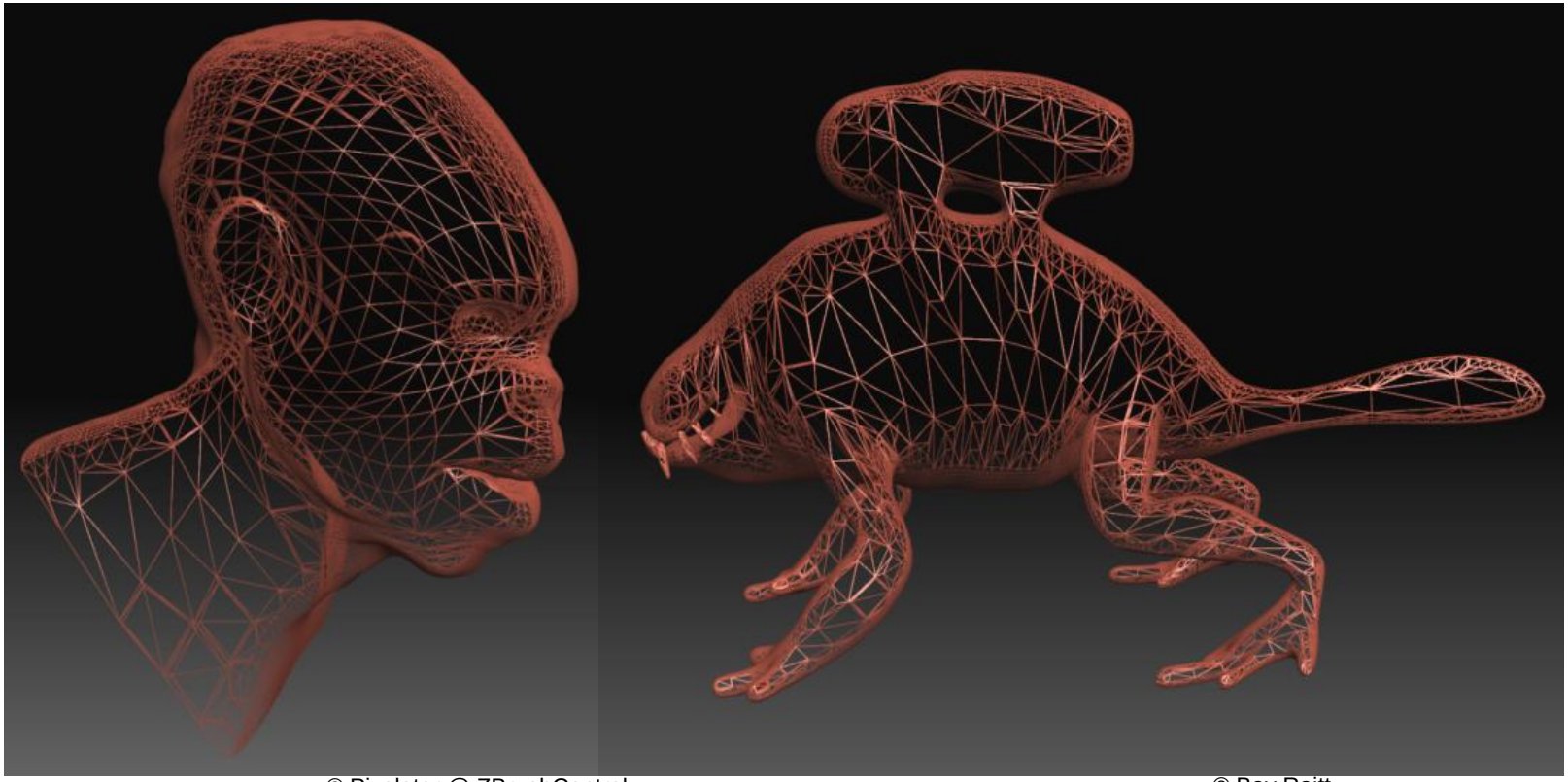
Hull Shader

- New patch primitive type
  - The only supported primitive when tessellation is enabled
  - Arbitrary vertex count (up to 32)
  - No implied topology
- Computes control points
- Computes tessellation factors



Adaptive Tessellation

- Curvature, view-dependent Level of Detail



© Pixolator @ ZBrushCentral

© Bay Raitt

Control Points Evaluation

- In all cases we can evaluate a control point as a weighted sum: $P_j = \sum(W_{ij} * V_i)$
- Pre-compute the weights for each topological connection type and store this information in a texture
- The hull shader invokes multiple threads and use one thread to compute one control point.

Control Points Evaluation

```
ACC_CONTROL_POINT SubDToParametricPatchHS(
InputPatch<CONTROL_POINT_OUTPUT, M> p,
                          uint tid : SV_OutputControlPointID,
                          uint pid : SV_PrimitiveID )
{
   ACC_CONTROL_POINT output;

   int topo = getPatchConnectivityID(pid);

   int num = getVertexCount(pid);

   float3 output.pos= float3(0,0,0);
   for (int i=0; i< num; i++)
   {
      int idx = getVertexIDinPatch(pid,i);

      int index = fetchIndexInStencil(topo, idx, tid);
      output.pos += p[i] * gStencil.Load(int3((index, 0,0));
   }
   return output;
}
```

connectivity type ID

the number of vertices in the patch primitive

use index global ordering

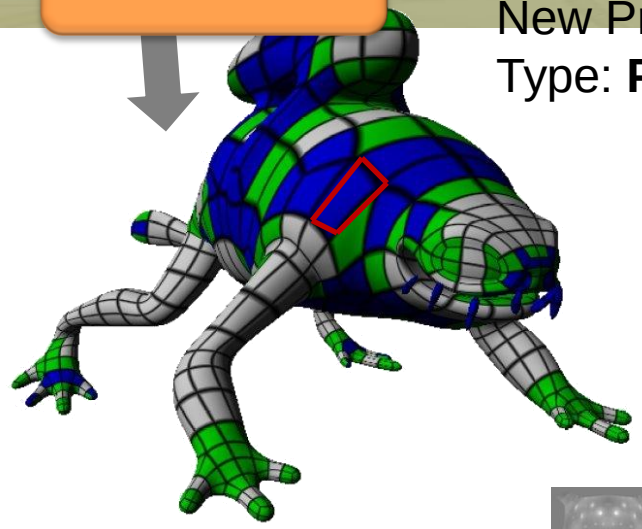
Compute one control point per thread

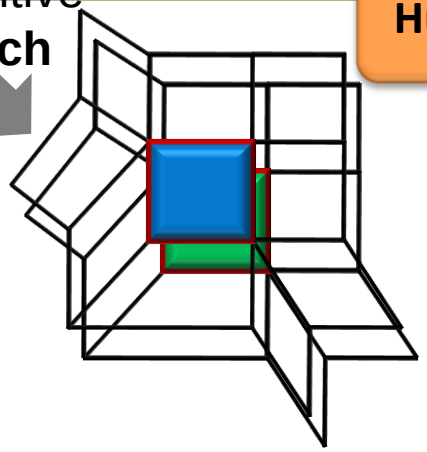
Direct3D 11 Tessellation

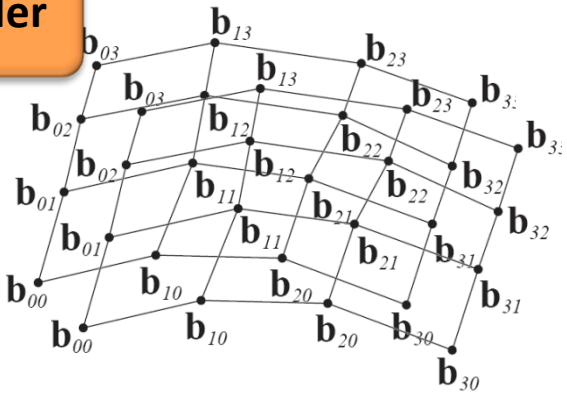
Vertex Shader

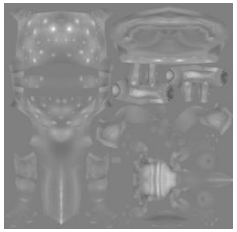
New Primitive
Type: **Patch**

Hull Shader



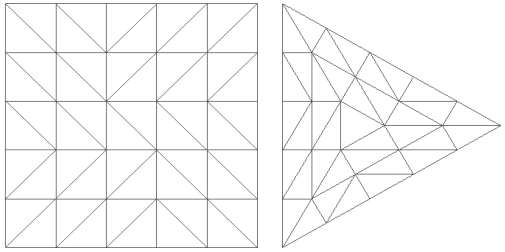


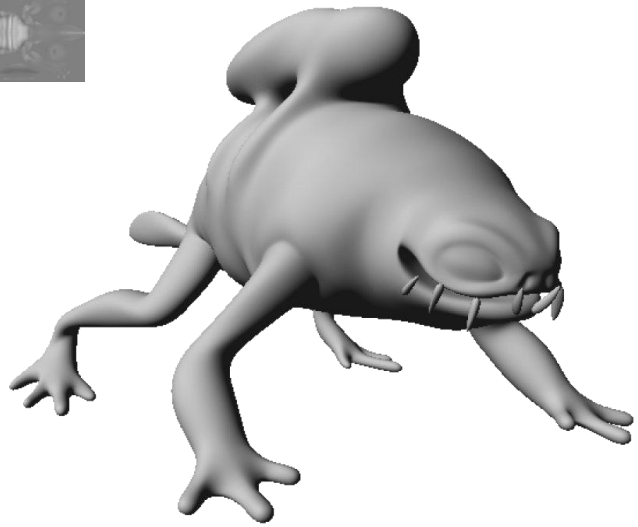




Tessellator

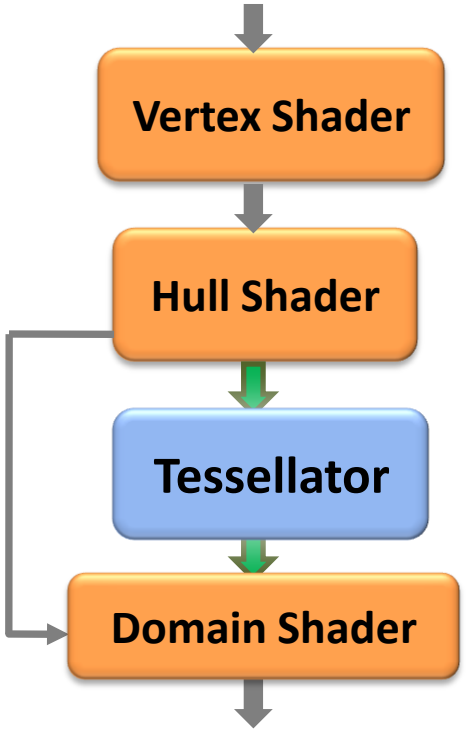
\+



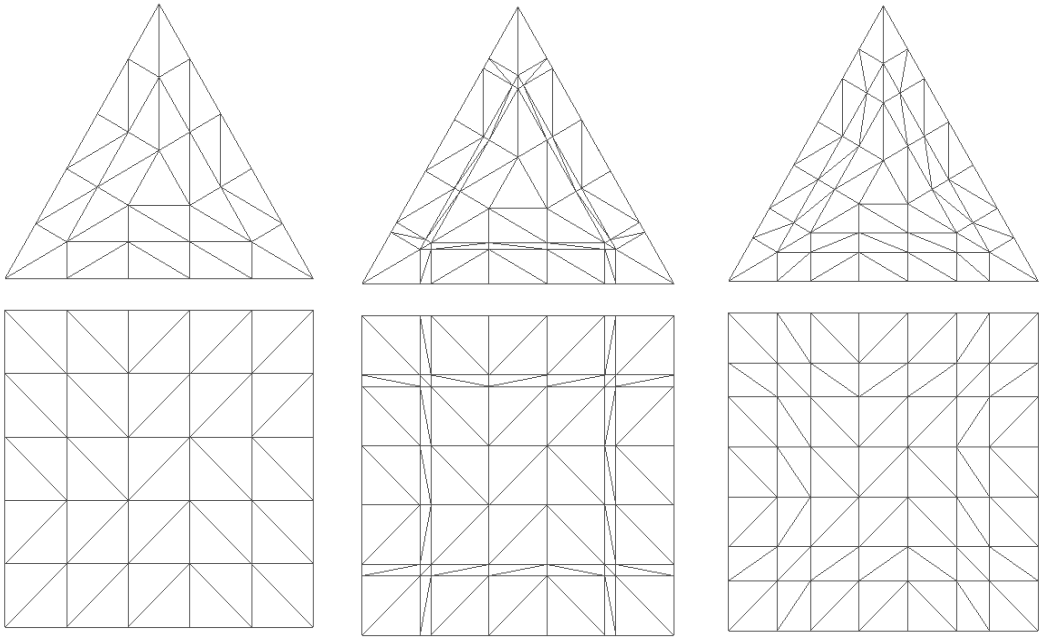


Tessellator

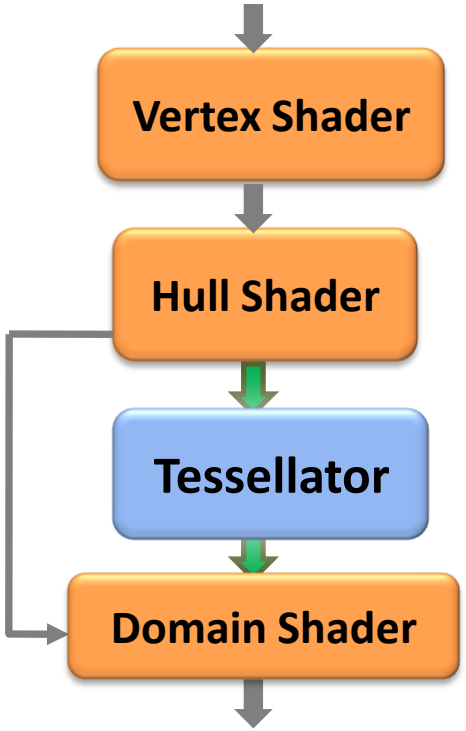
- Fixed function stage, but configurable
- Domains:
  - Triangle
  - Quad
  - Isolines
- Spacing:
  - Discrete
  - Continuous(fractional)
  - Pow2



Tessellator



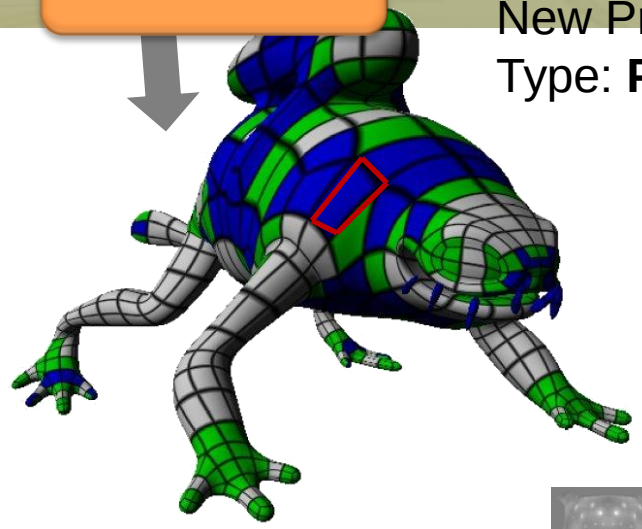
Level 5 Level 5.4 Level 6.6

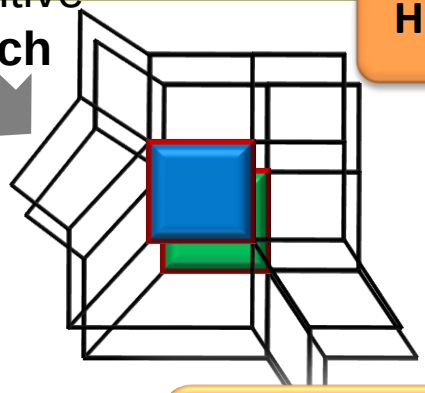


Direct3D 11 Tessellation

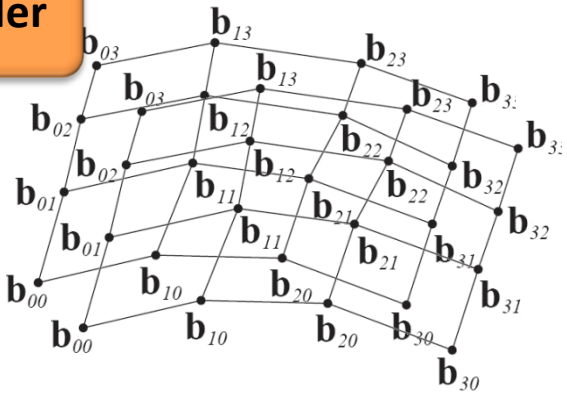
Vertex Shader

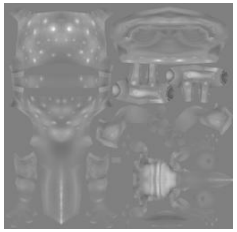
New Primitive
Type: **Patch**



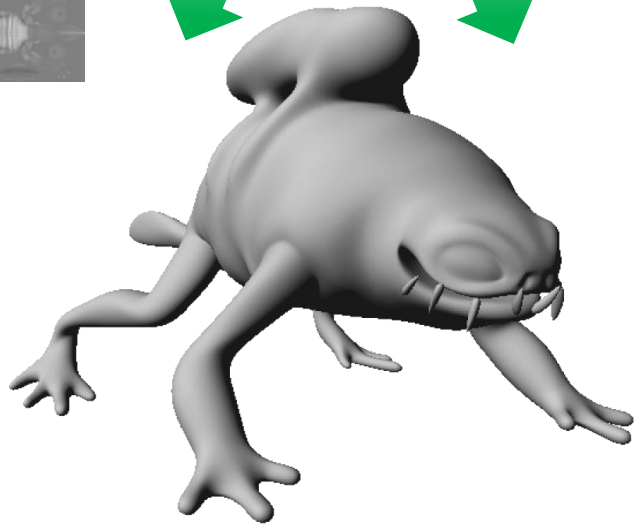


Hull Shader



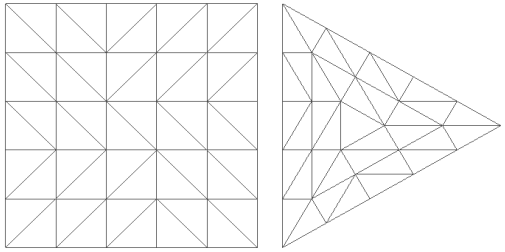


Domain Shader



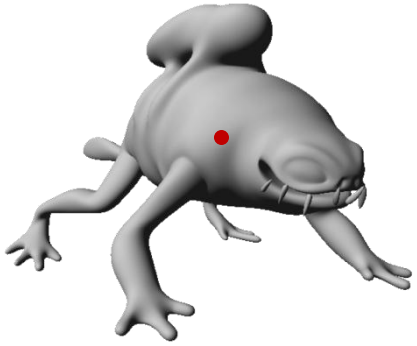
Tessellator

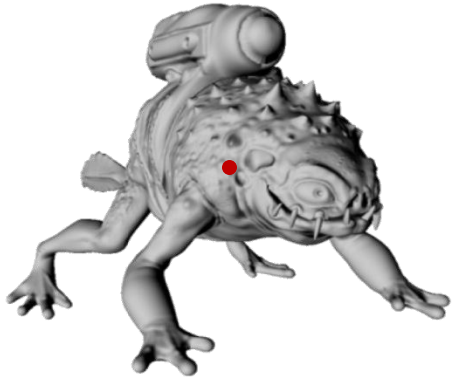
+

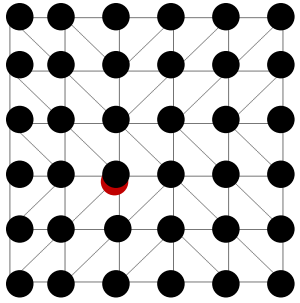


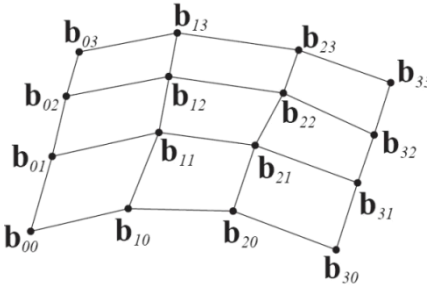
Domain Shader

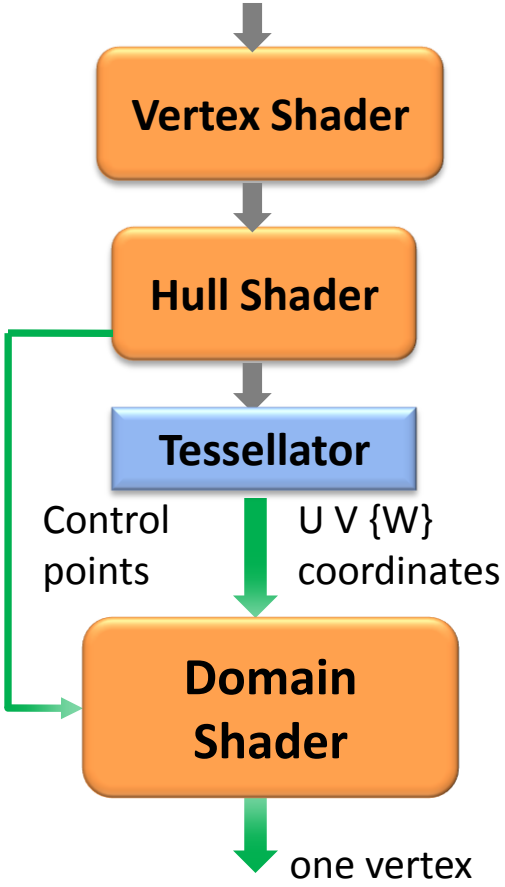
- Evaluate surface given parametric UV{W} coordinates
- Apply displacements
- One invocation per generated vertex



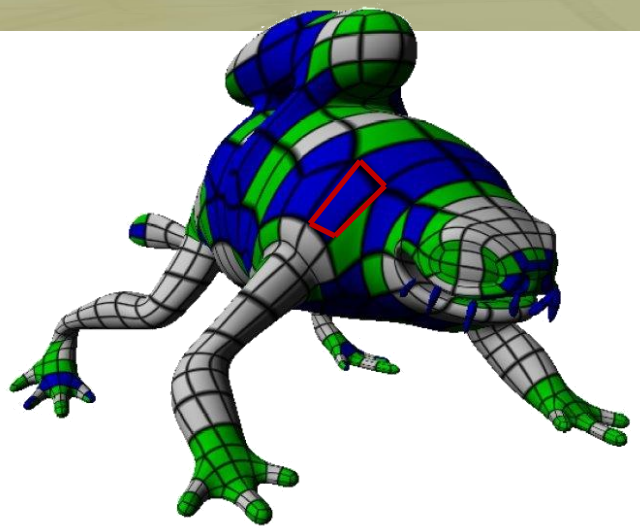


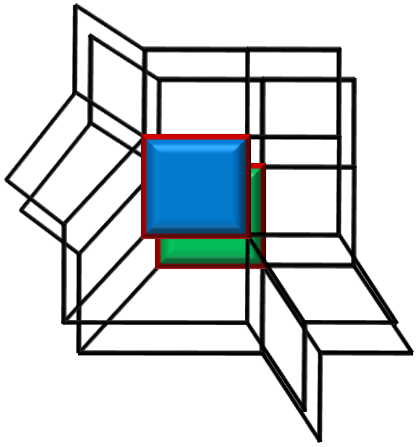


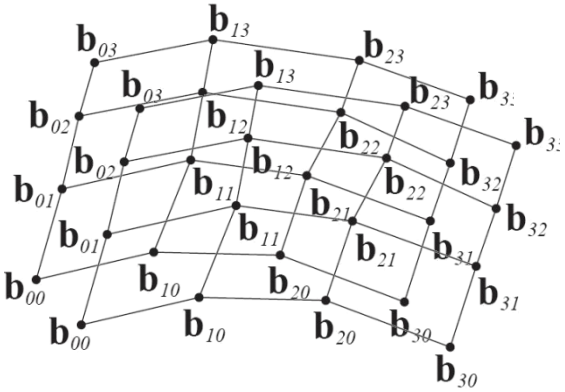


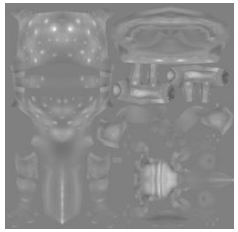


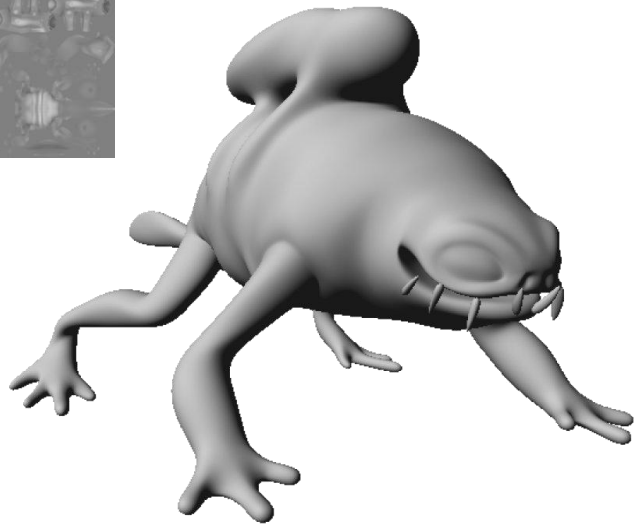
Tessellation Process



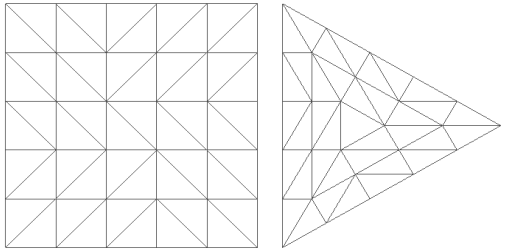








+

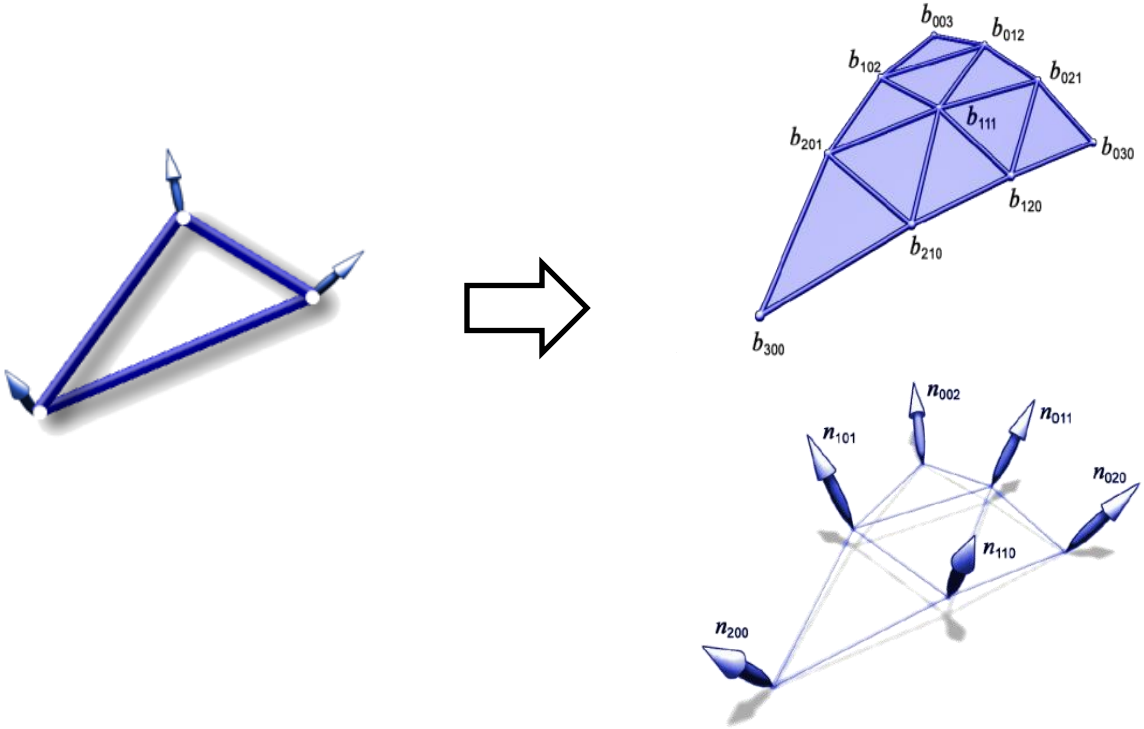


Patch Construction Schemes

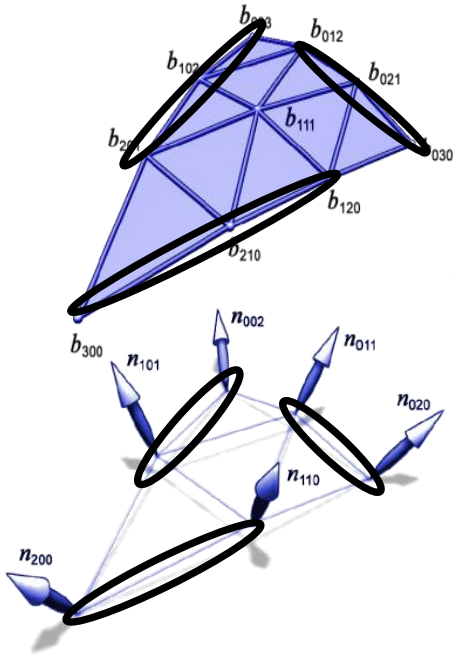
- PN Triangles

  by Alex Vlachos, Jörg Peters, Chas Boyd, and Jason Mitchell

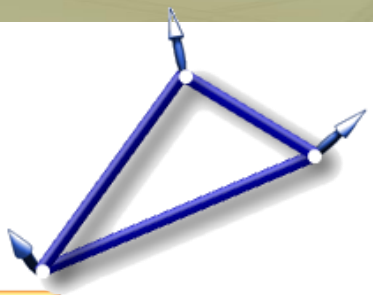
  "**Curved PN Triangles**", I3D 2001: Proceedings of the 2001 Symposium on Interactive 3D Graphics, pages 159-166, 2001.



PN Triangles on Direct3D 11 Pipeline



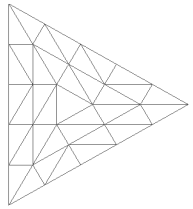
HS input:



Hull Shader

Tessellation factors

Tessellator

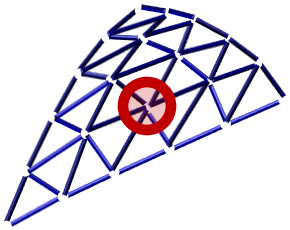


Domain Shader

DS Input from Tessellator:

- uvw coordinates for one vertex

DS Output:

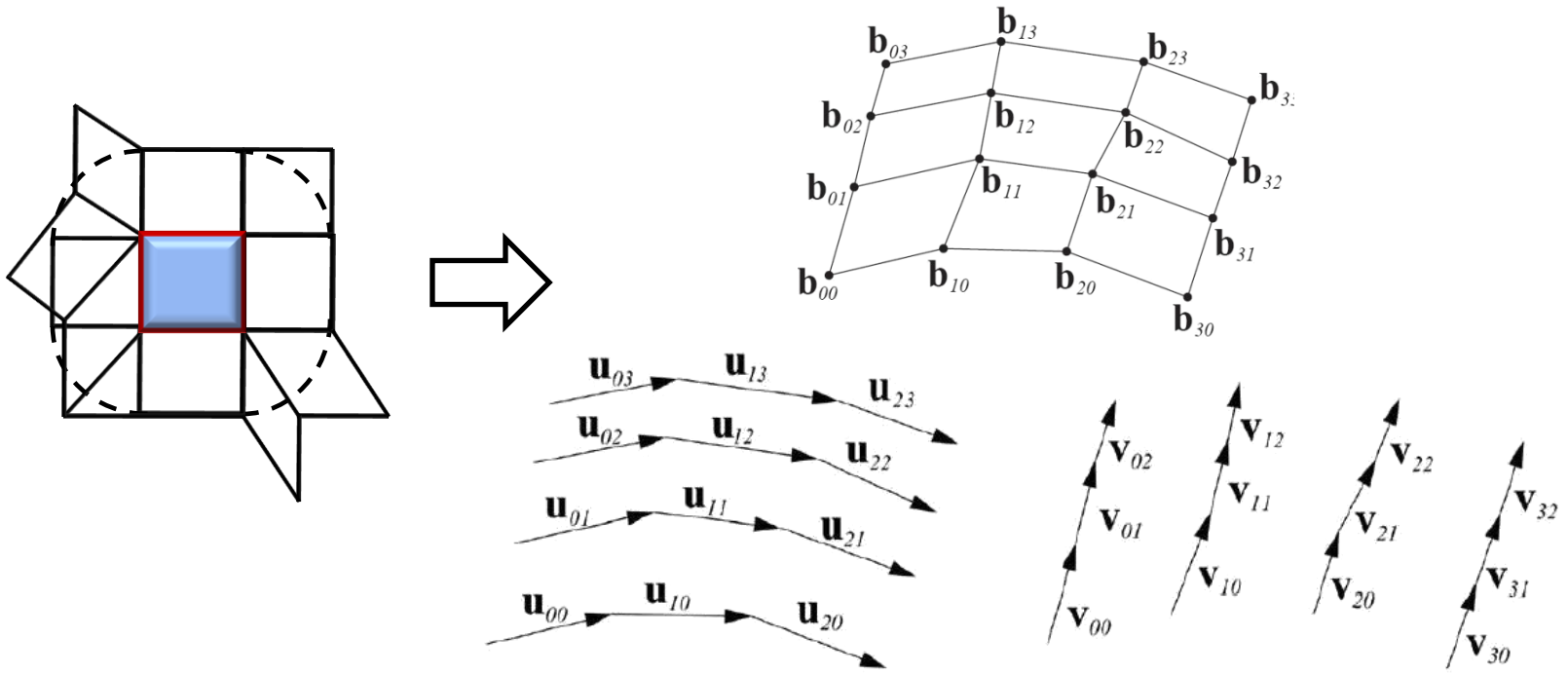


Patch Construction Schemes

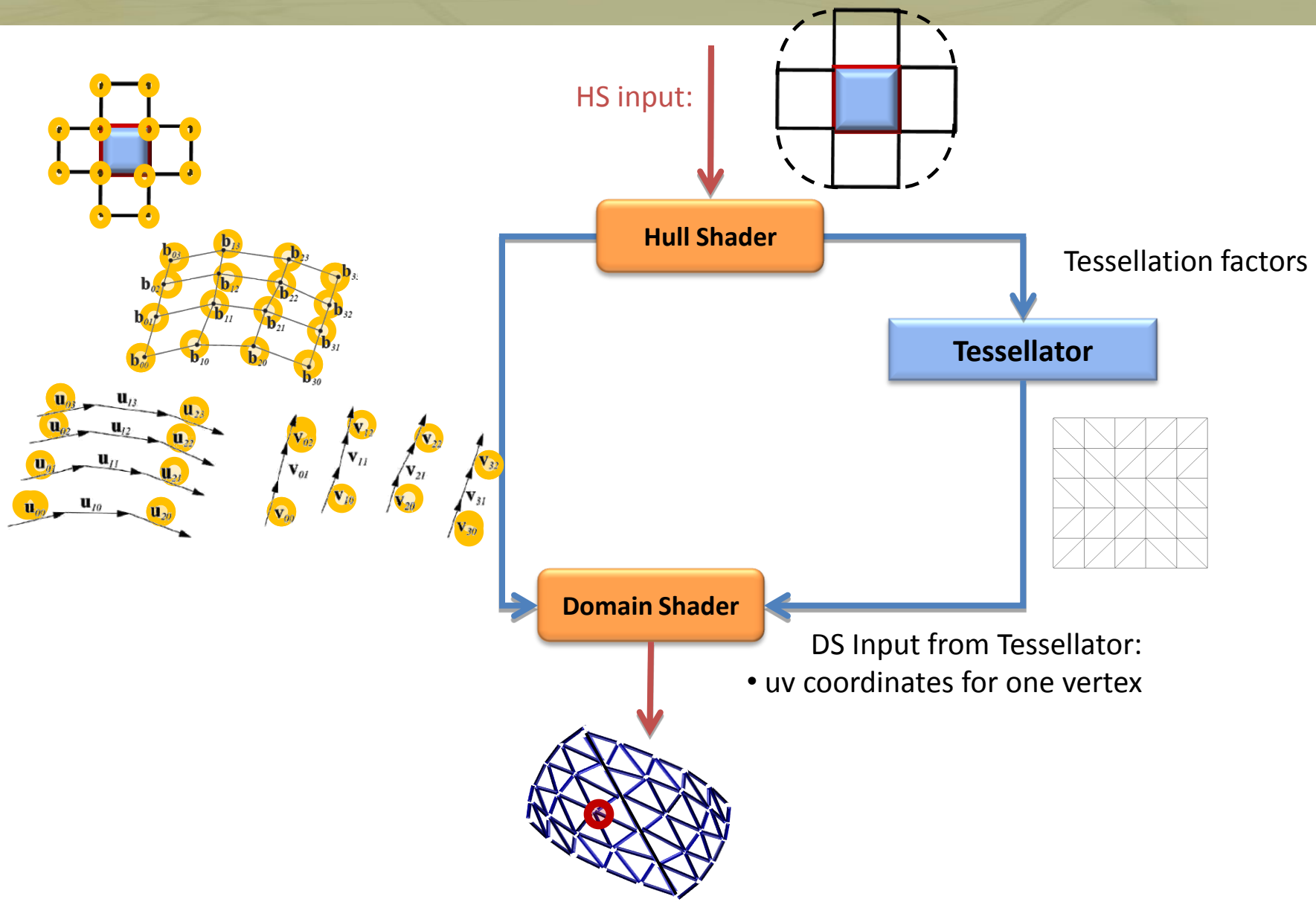
- ACC Patches

  by Charles Loop and Scott Schaefer

  "**Approximating Catmull-Clark Subdivision Surfaces with Bicubic Patches**" , *ACM Transactions on Graphics*, Vol. 27 No. 1 Article 8 March 2008.



ACC Patch on Direct3D 11 Pipeline

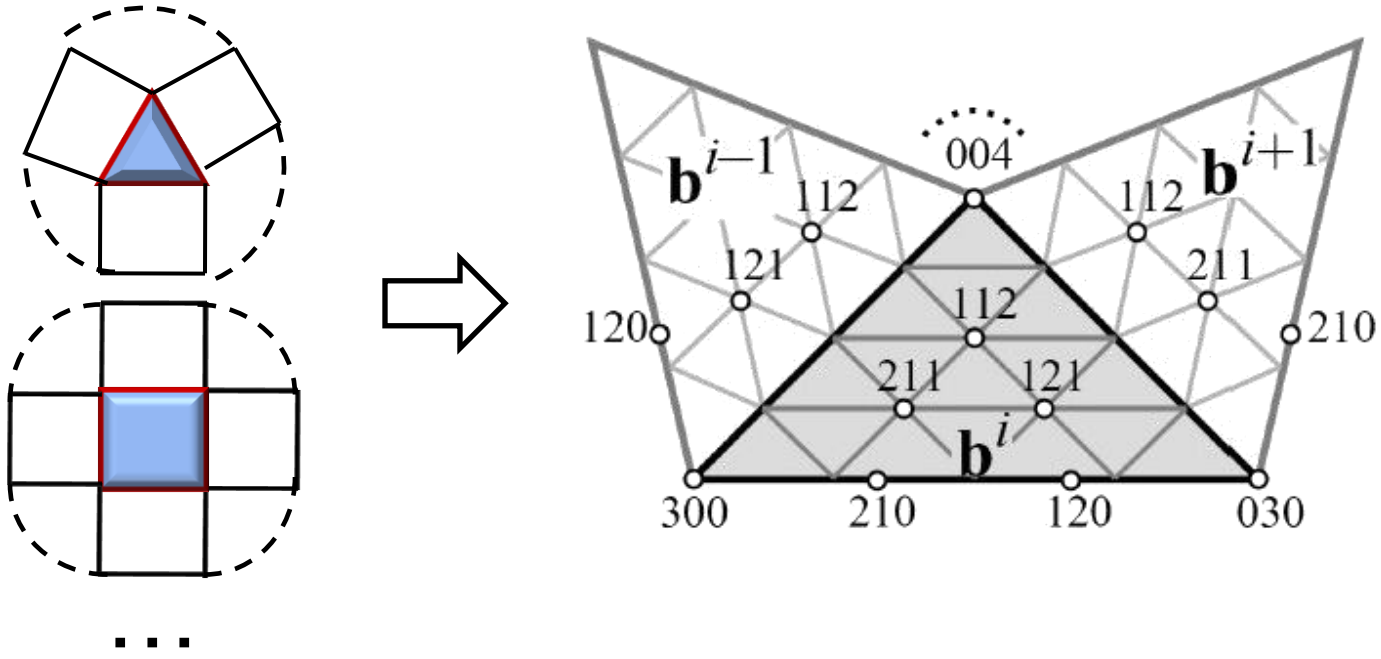


Patch Construction Schemes

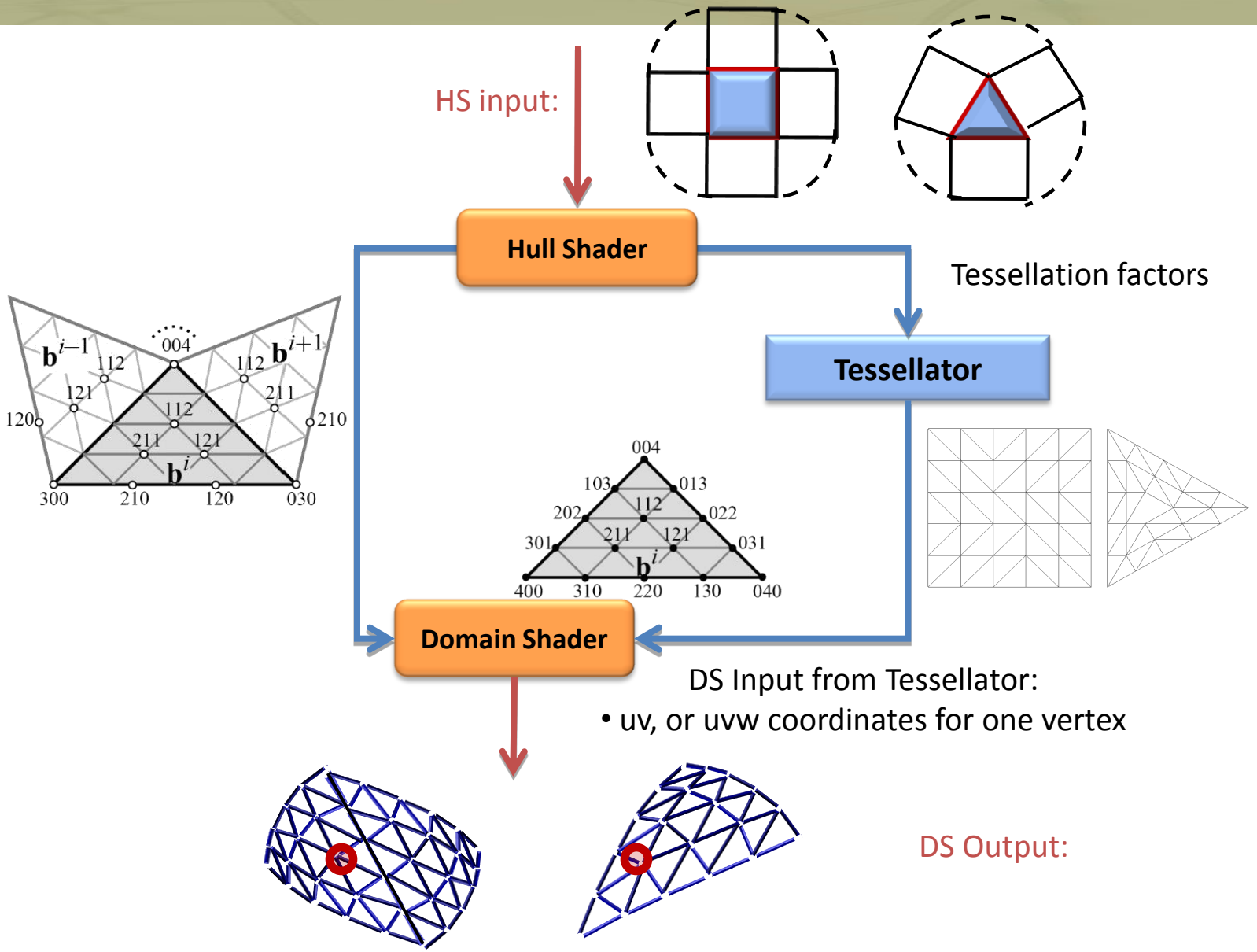
- Pm Patches

  by Ashish Myles, Tianyun Ni and Jörg Peters

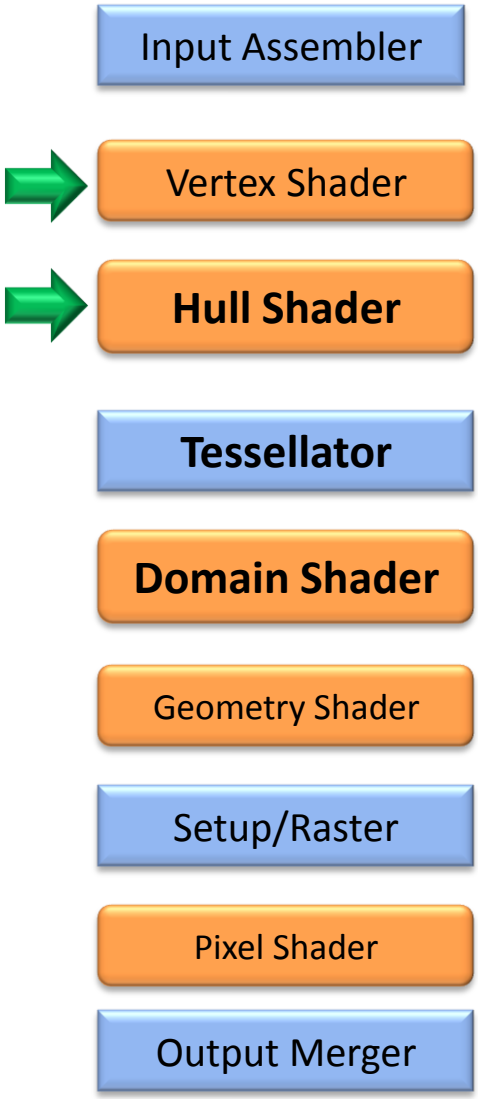
  *"**Fast Parallel Construction of Smooth Surfaces from Meshes with Tri/Quad/Pent Facets**", Symposium on Geometry Processing (SGP),* Copenhagen, Denmark, January 2 - 4, 2008.



Pm – Patch on Direct3D 11 Pipeline



Instanced Tessellation on Current Hardware



Rendering Pass 1: Animation

Input Assembler

Vertex Shader

Rendering Pass 2: Patch Construction

Input Assembler

Vertex Shader

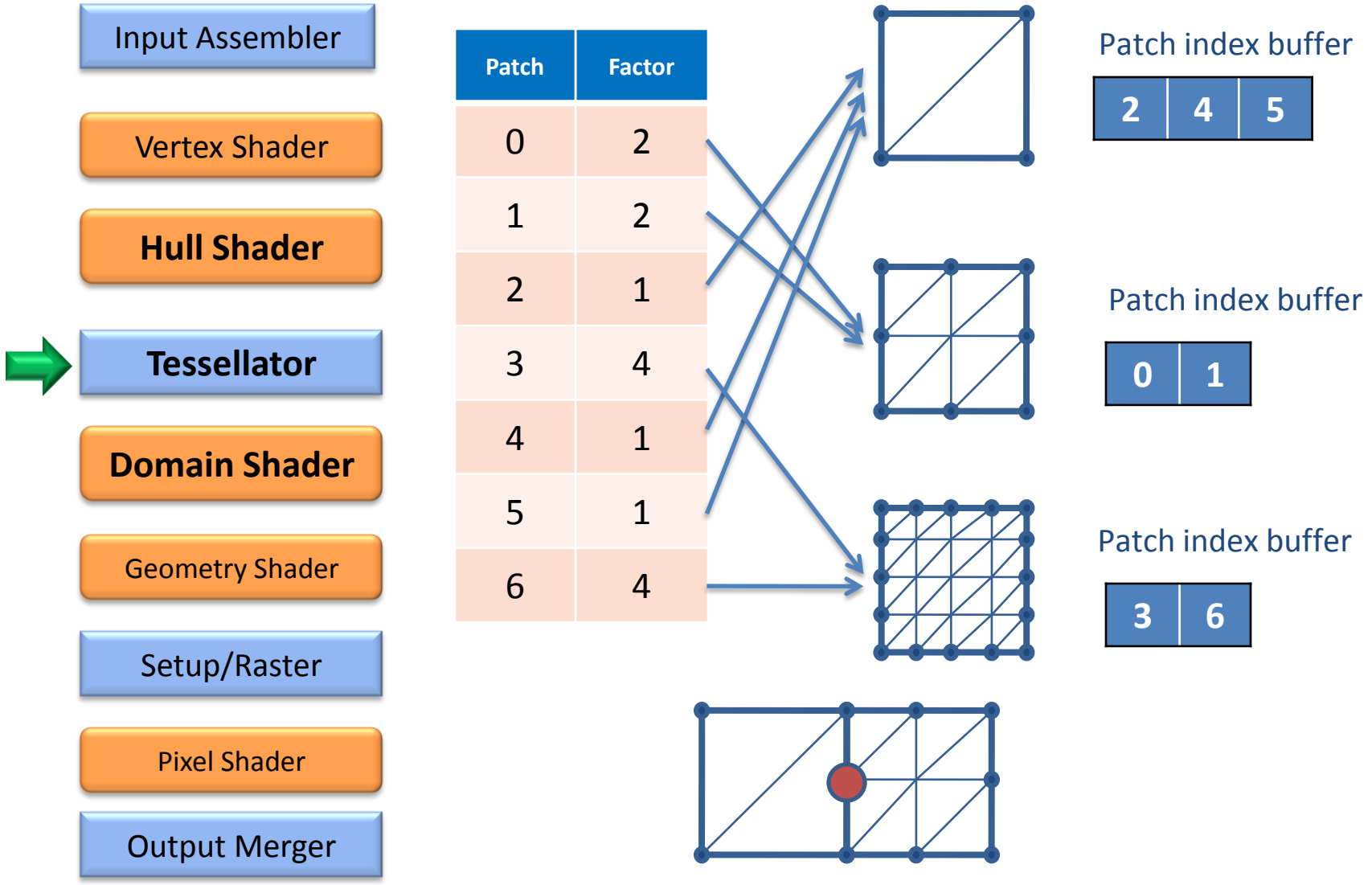
Geometry Shader

Rendering Pass 3: Compute TF

Input Assembler

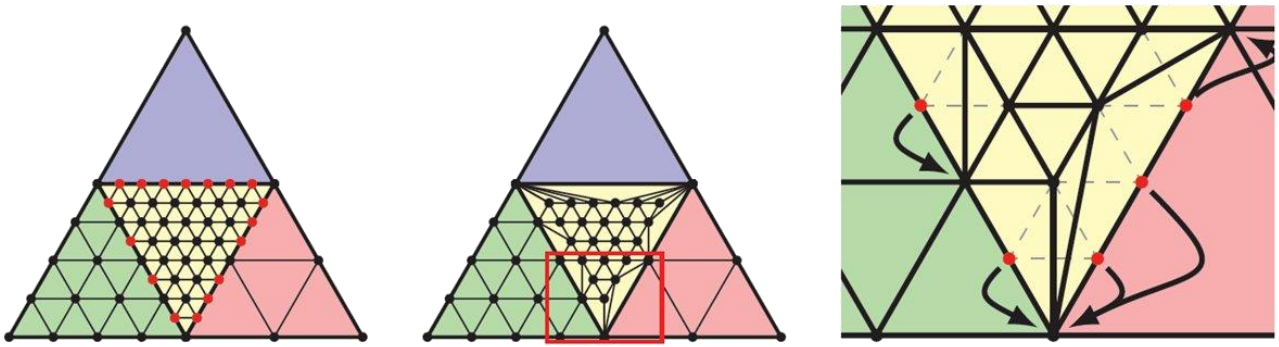
Vertex Shader

Instanced Tessellation on Current Hardware

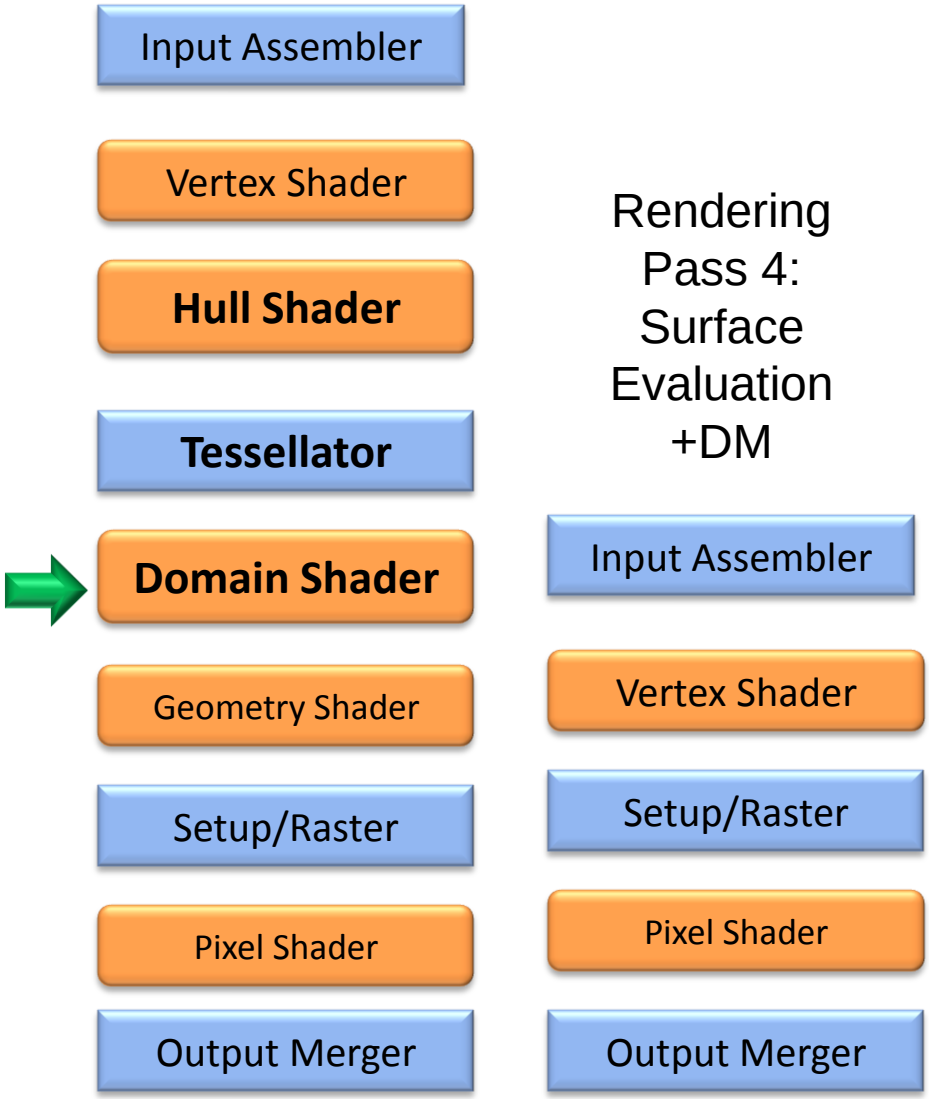


Adaptive Tessellation on Current Hardware

- **Generic Mesh Refinement On GPU**
  http://iparla.labri.fr/publications/2005/BS05/GenericMeshRefinementOnGPU.pdf
- **Generic Adaptive Mesh Refinement**
  http://http.developer.nvidia.com/GPUGems3/gpugems3_ch05.html
- **Semi-uniform Adaptive Patch Tessellation**
  http://sintef.org/project/Heterogeneous%20Computing/preprints/topofix-draft.pdf



Instanced Tessellation on Current Hardware



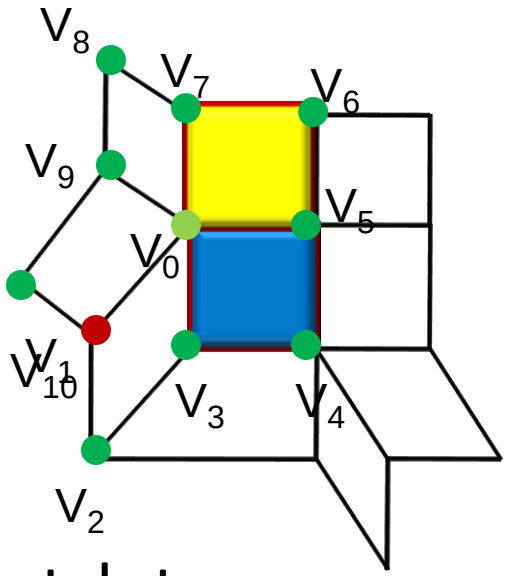
- In the vertex shader
  - Load patch index from bucket's patch list
  - Load edge tessellation level to stitch boundaries
  - Load control points to evaluate surface
  - Apply Displacement Mapping

Watertight Tessellation

- Floating point precision issue
  - Addition is not always commutative as it should be
  - Special care has to be taken to obtain watertight results to prevent cracks
  - Tessellation process involves 3 stages
    - Patch Construction
    - Surface Evaluation
    - Displacement Mapping

Watertight Patch Construction

- Control Points Evaluation
  - Control points type: corner, edge, face
  - In all cases we can evaluate a control point as weighted sum: $P_j = \sum(W_{ij} * V_i)$
  - Needs consistent ordering of the summation



  - Different patch types

Watertight Surface Evaluation

Positions:

$P(u,v) = \sum b_i B_i(u,v)$

Problem:

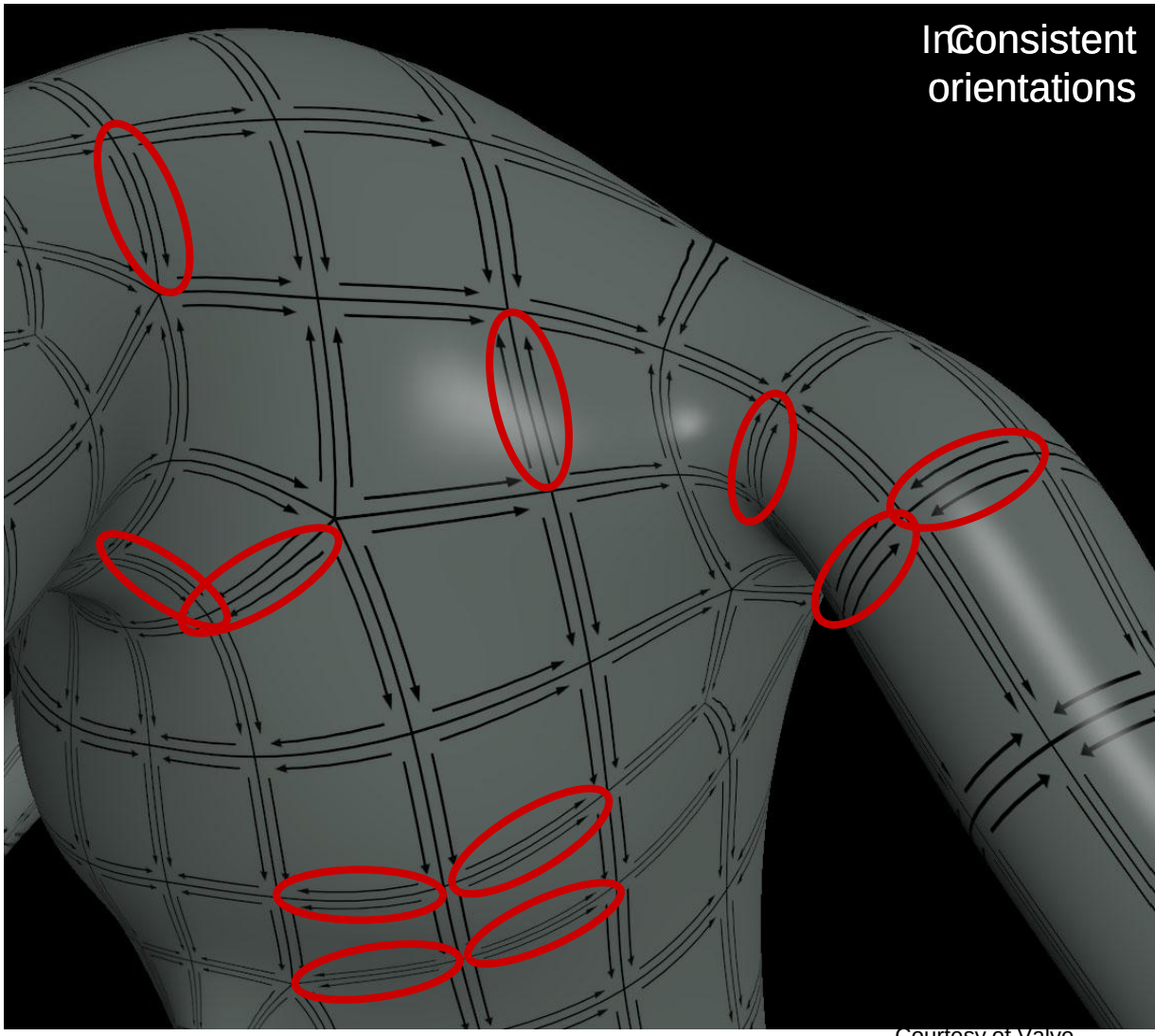
a+b+c != c+b+a

Solution 1:

All computations need to done in consistent parametric orientation

Solution 2:

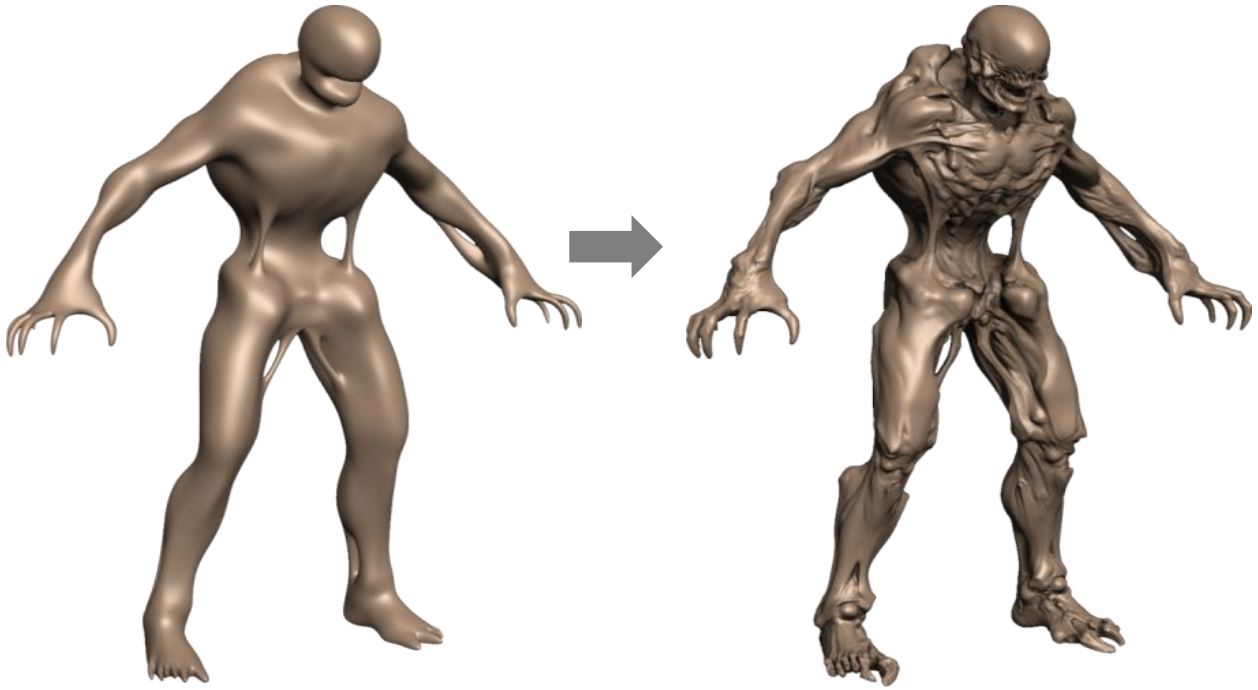
Symmetric evaluation



Courtesy of Valve

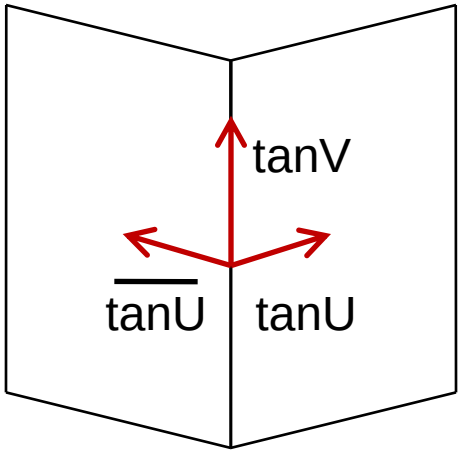
Watertight Displacement

- Displacement Mapping
  - Sample displacement value from a texture
  - Displace vertex along its normal



Watertight Displacement

- Watertight normals
  - Cross product of a pair of tangnet, bitangent vectors
  - All three vectors should be co-planar
  - Problem: cross(tanU,tanV) ≠cross(tanV, $\overline{\text{tanU}}$)
  - Discontinuities occur at shared corners and edges
  - Define corner and edge ownership

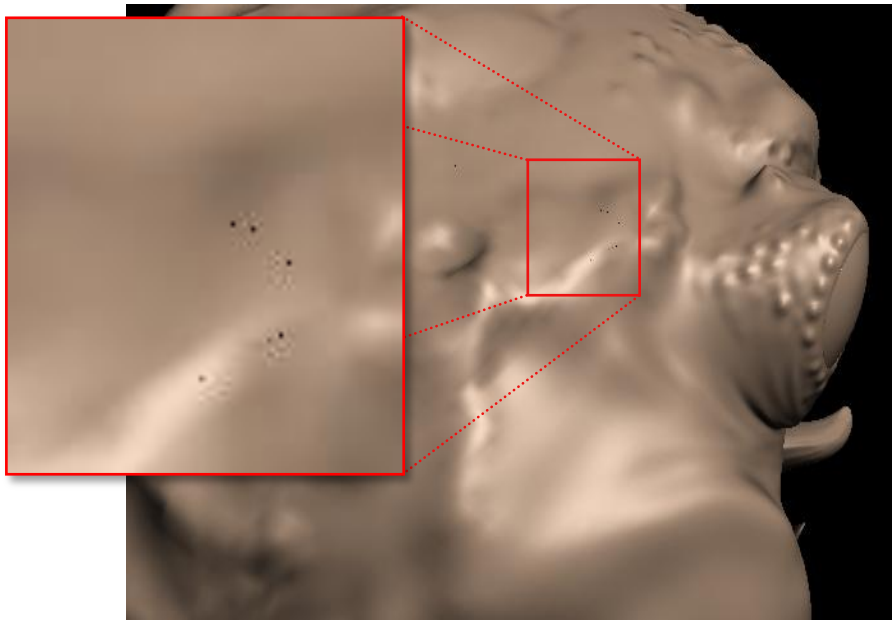


Watertight Displacement

Problem:

Non-watertight Texture Seams

- Due to bilinear discontinuities
- Varying floating point precision on different regions of the texture map
- Seamless parameterization removes bilinear artifacts, but does not solve floating point precision issues

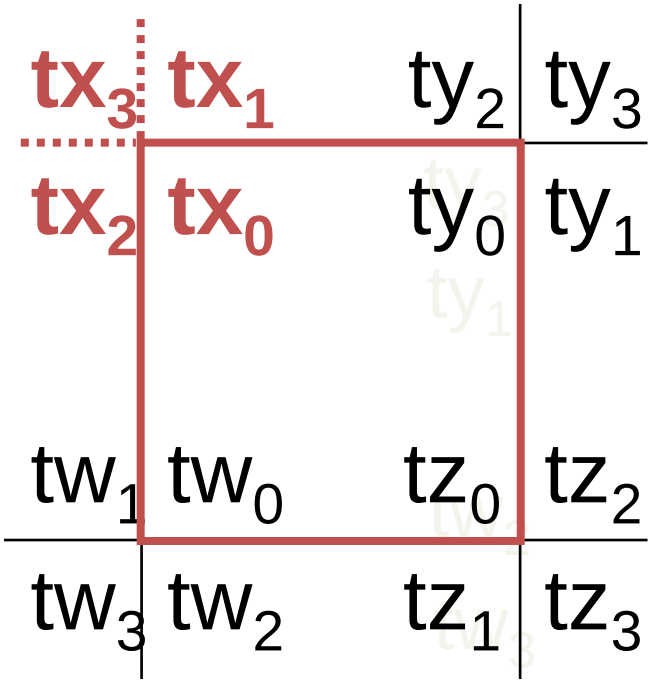


Solution:

Define patch ownership of the seams

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



Watertight Surface Evaluation

Suggested Reading:

- **Tessellation of Subdivision Surfaces in DirectX 11 (**Gamefest 08) http://developer.nvidia.com/object/gamefest-2008-subdiv.html
- **Next-Generation Rendering of Subdivision Surfaces (**Siggraph08) http://developer.nvidia.com/object/siggraph-2008-Subdiv.html

Live Demo

Instanced Tessellation

GPU Patch Construction

Q & A

Tianyun Ni
tni@nvidia.com

Ignacio Castaño
icastano@nvidia.com