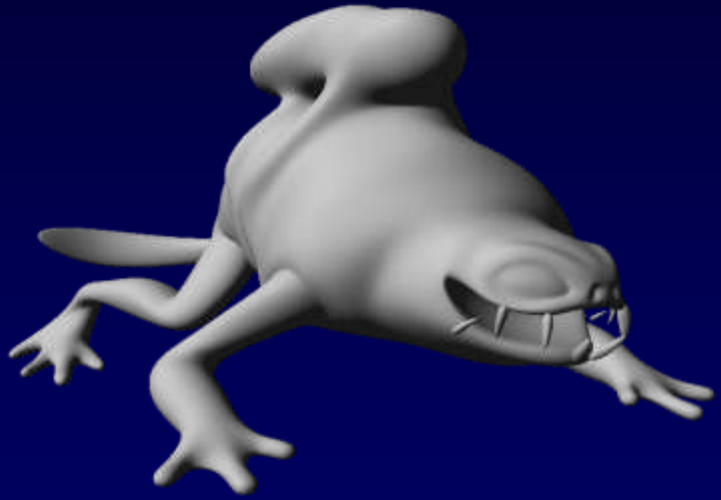
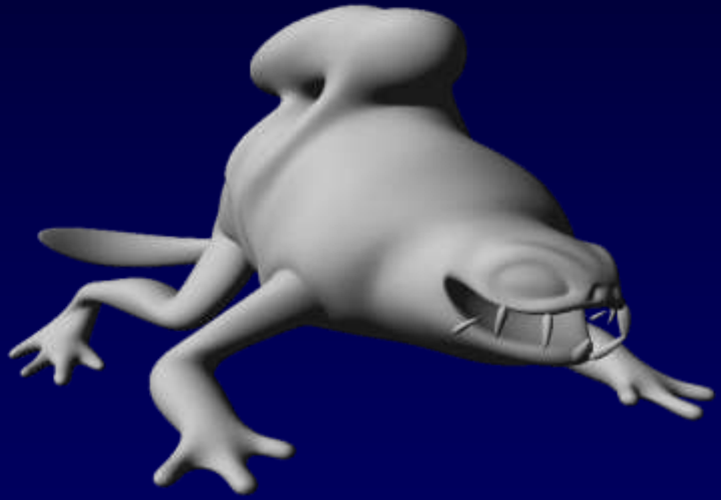
Approximate Catmull-Clark Patches

Scott Schaefer

Charles Loop





TAMU
Computer
Science

Microsoft
Research

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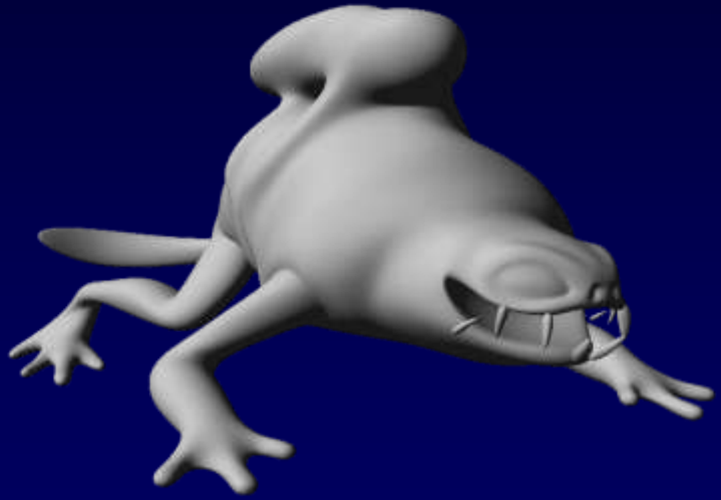
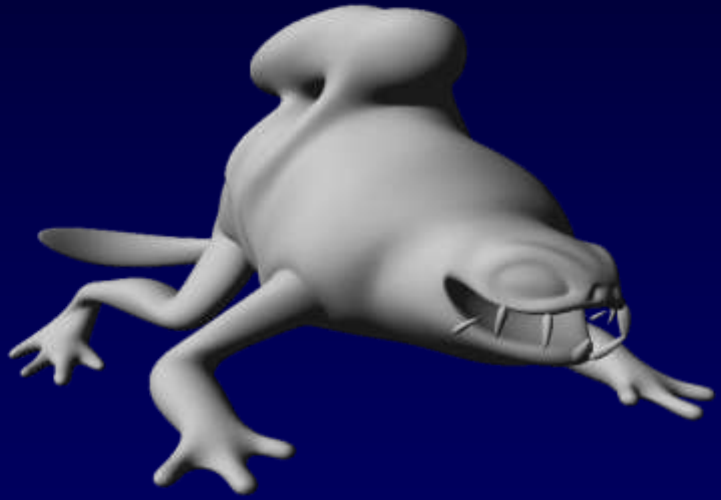


Catmull-Clark Surface



ACC-Patches

TAMU Computer Science

Microsoft Research

Polygon Models

- Prevalent in game industry
- Very fast to render
- Not smooth (faceted)
- Complicated LOD management
- High-resolution models require lots of band-width and computational resources

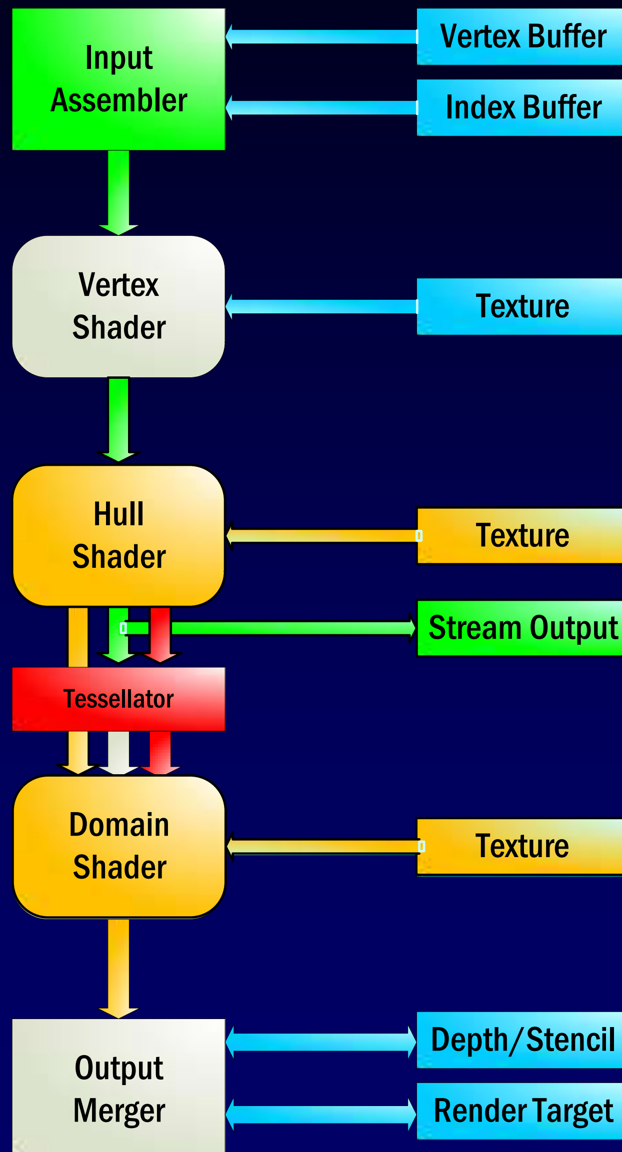
Goal: Fast Smooth Surfaces

- Eliminate faceting artifacts
- Animate low-res representation
- Let GPU worry about LOD

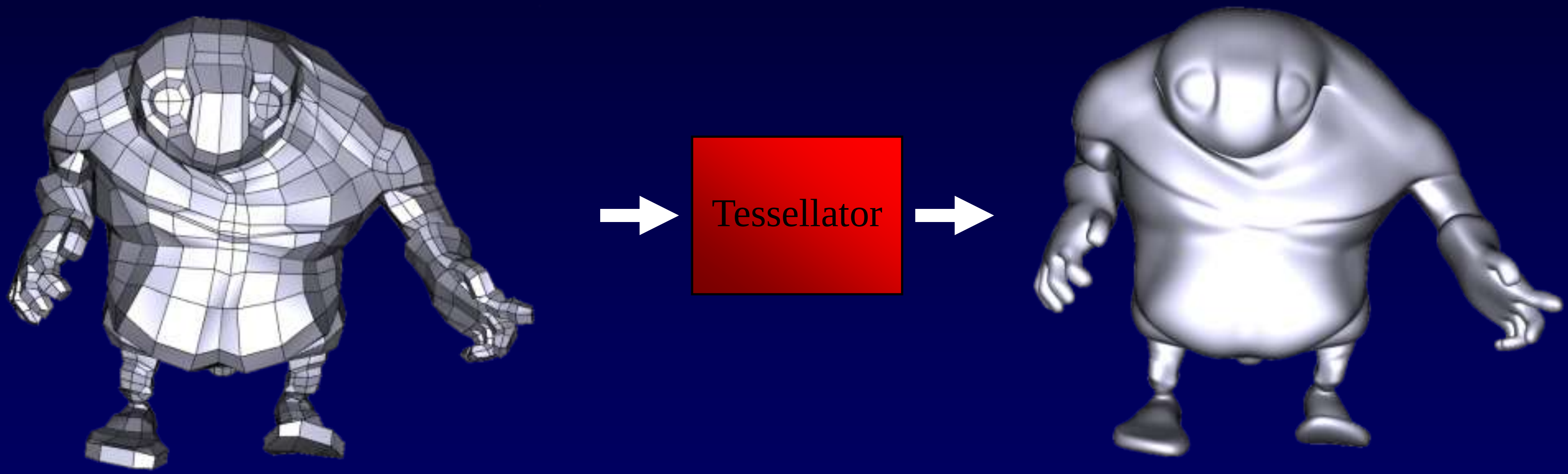
Current

Future

DirectX 10 Pipeline



Tessellator Unit



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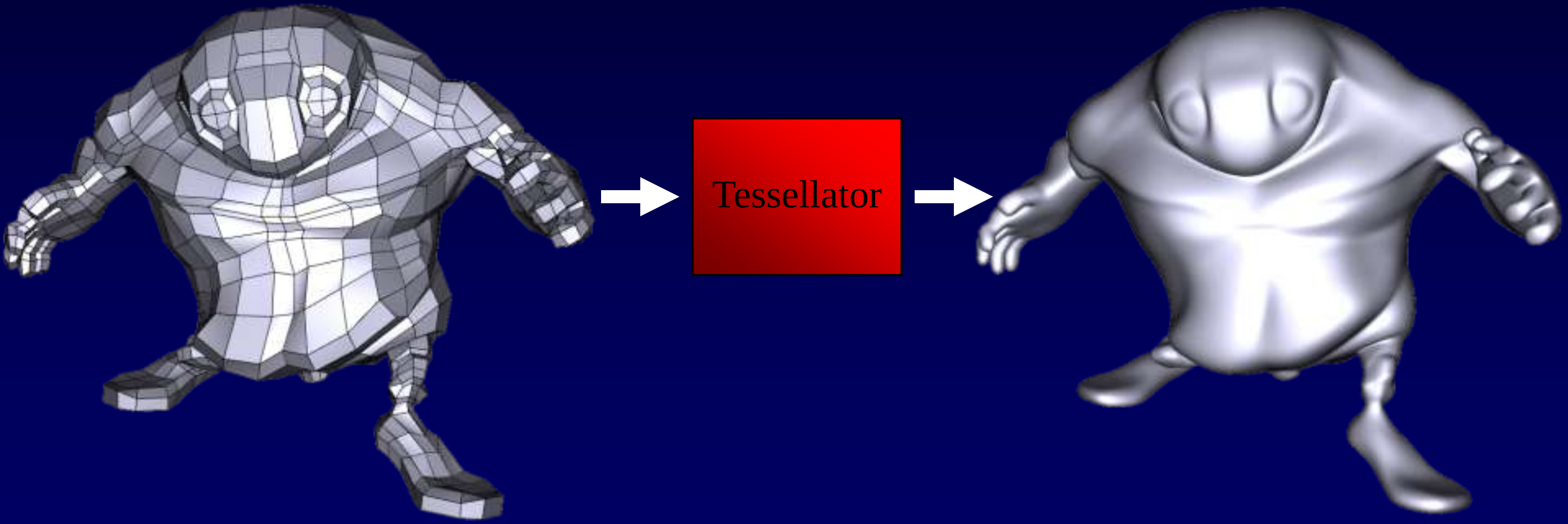
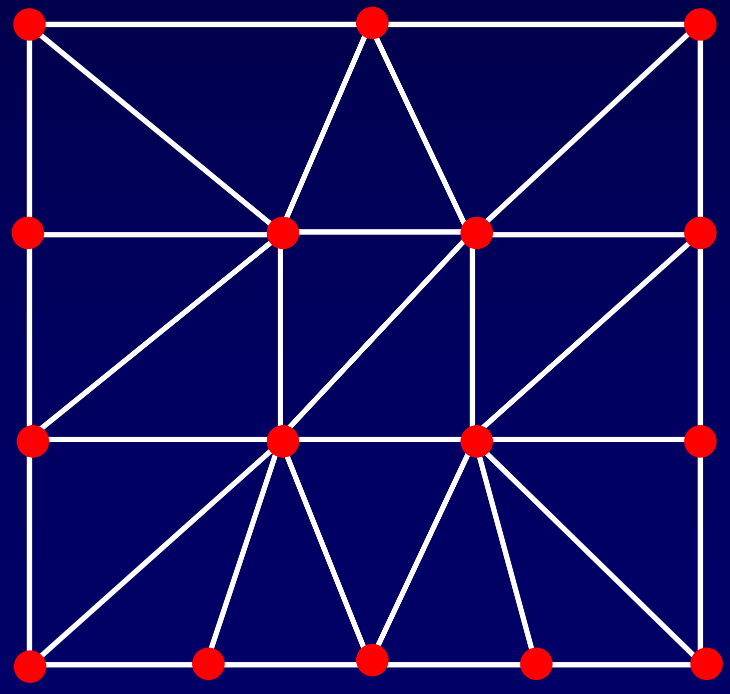


Domain Shader

- Tessellation factor per edge
- Called for each vertex of the sample pattern
- Early form in the XBox 360

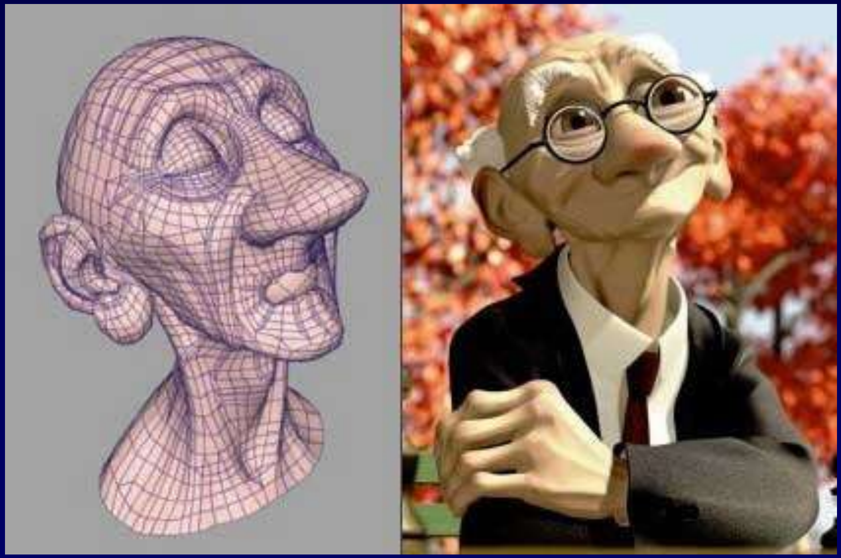


```
DS_OUT DS(float2 uv  : BARYCENTRIC,
                  int patchInd : INDEX)
{
   DS_OUT Out = (DS_OUT)0;

   // fetch data for patch #patchInd

   // evaluate patch at uv

   return Out;
}
```

Subdivision Surfaces

- Used in movie and game industries
- Supported by most 3D modeling software

Toy Story © Disney / Pixar



Geri’s Game © Pixar Animation Studios

Subdivision Surfaces

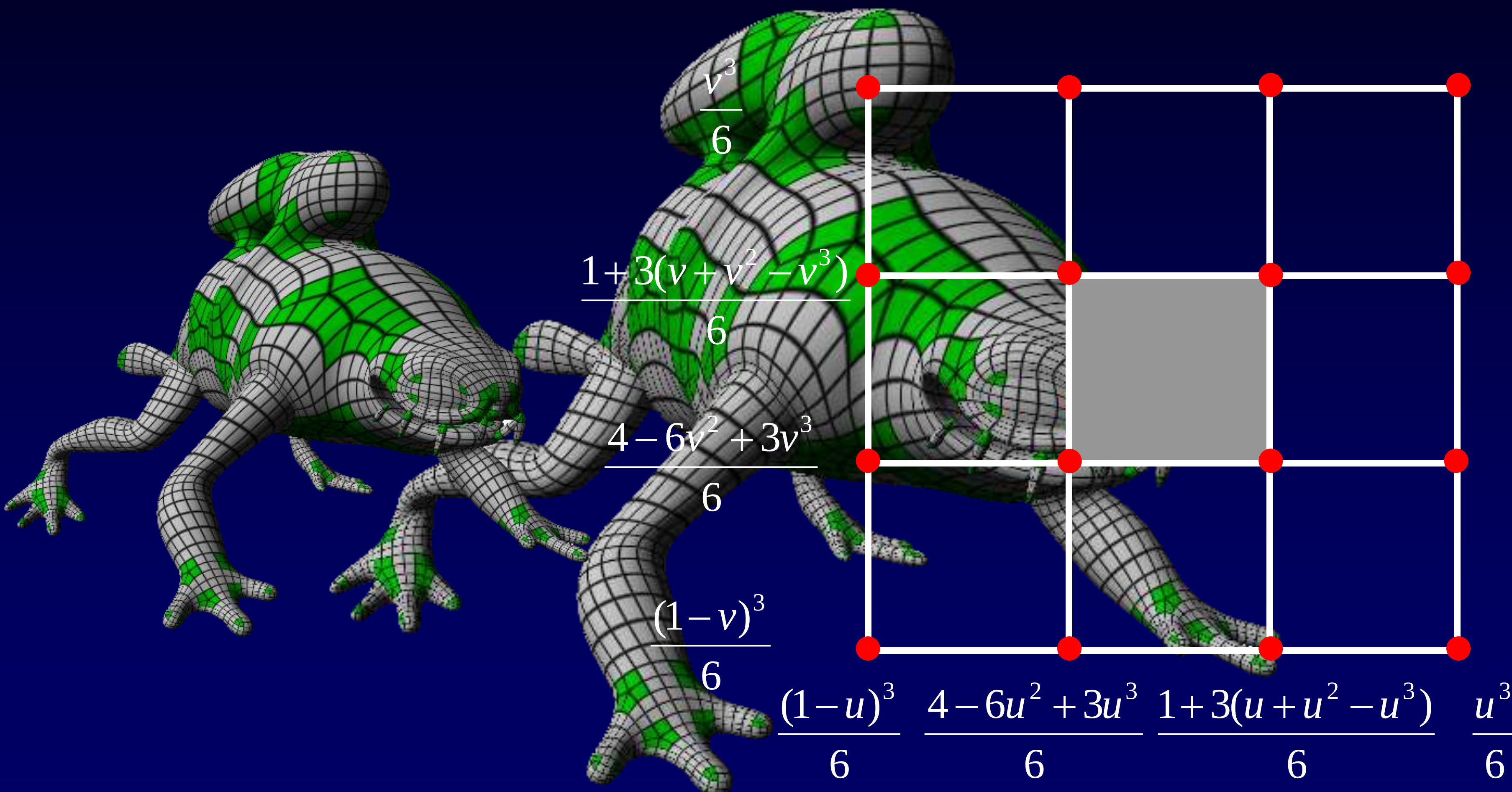
- Set of rules S that recursively act on a shape p^0

$$p^{k+1} = S\, p^k$$

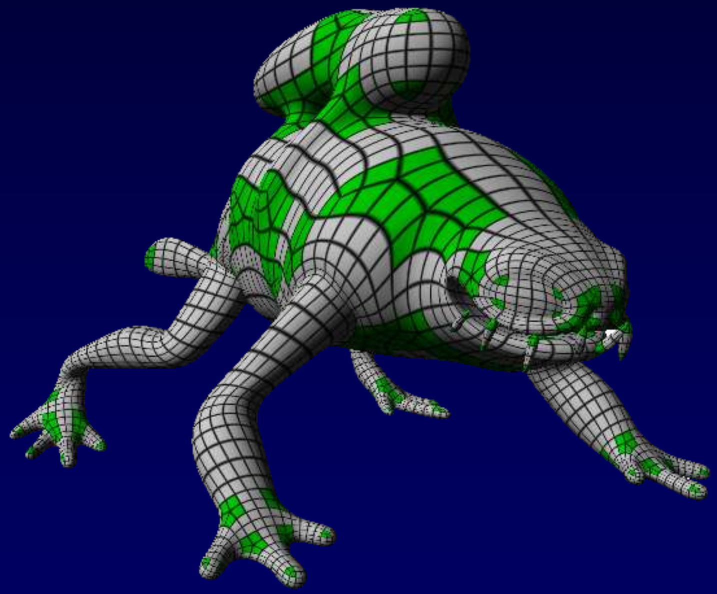
- Arbitrary topology surfaces
- Smooth everywhere

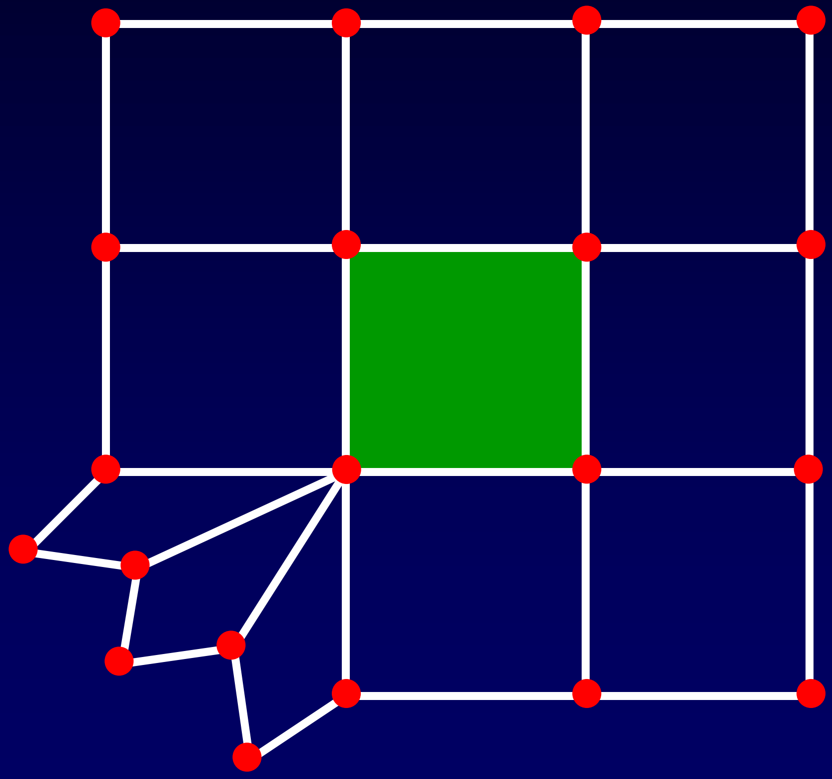
p^0 p^1 p^k

Catmull-Clark Surfaces

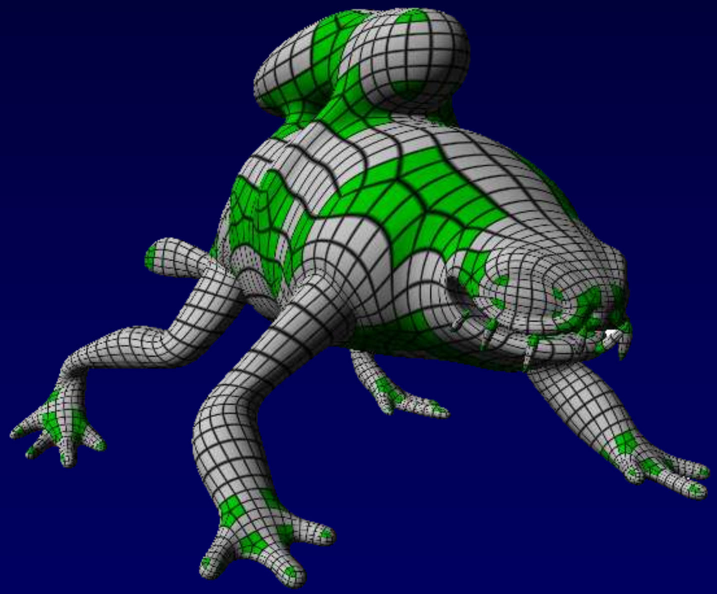


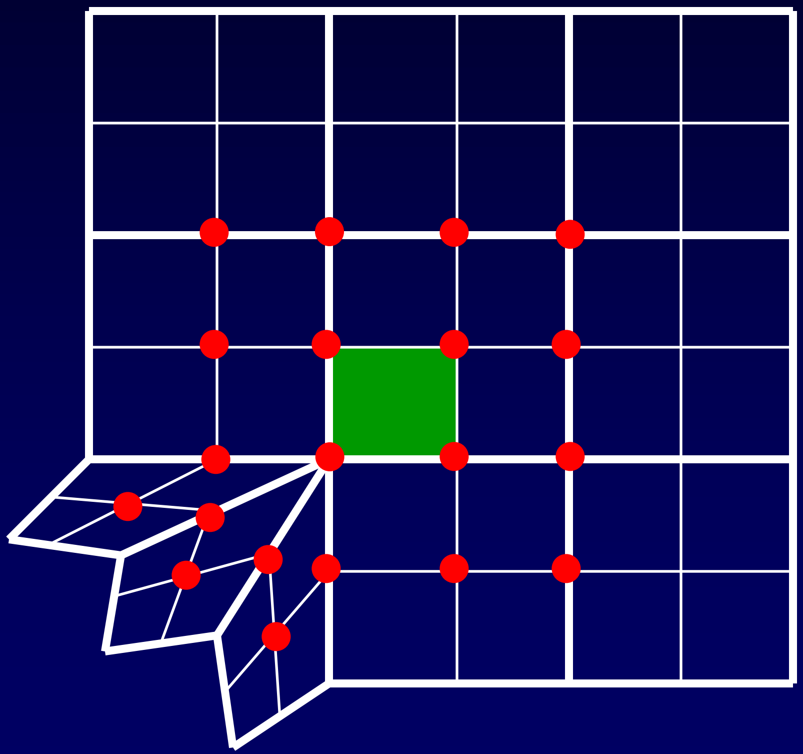
Catmull-Clark Surfaces





Catmull-Clark Surfaces





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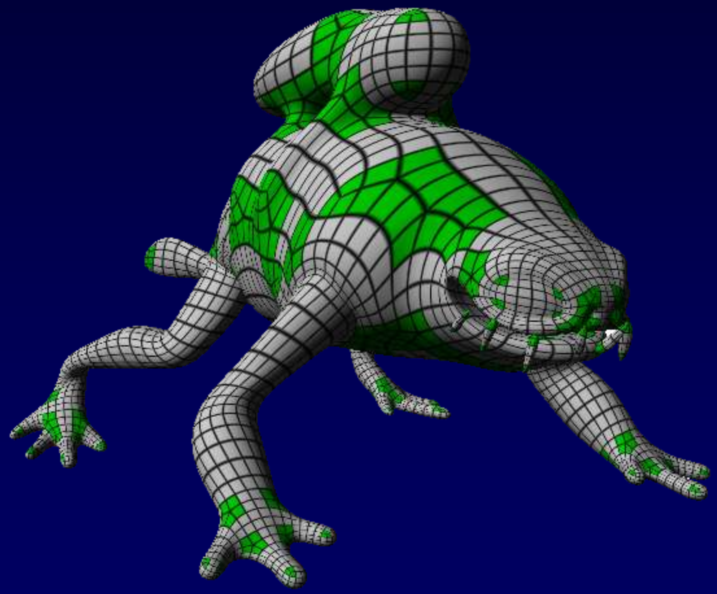

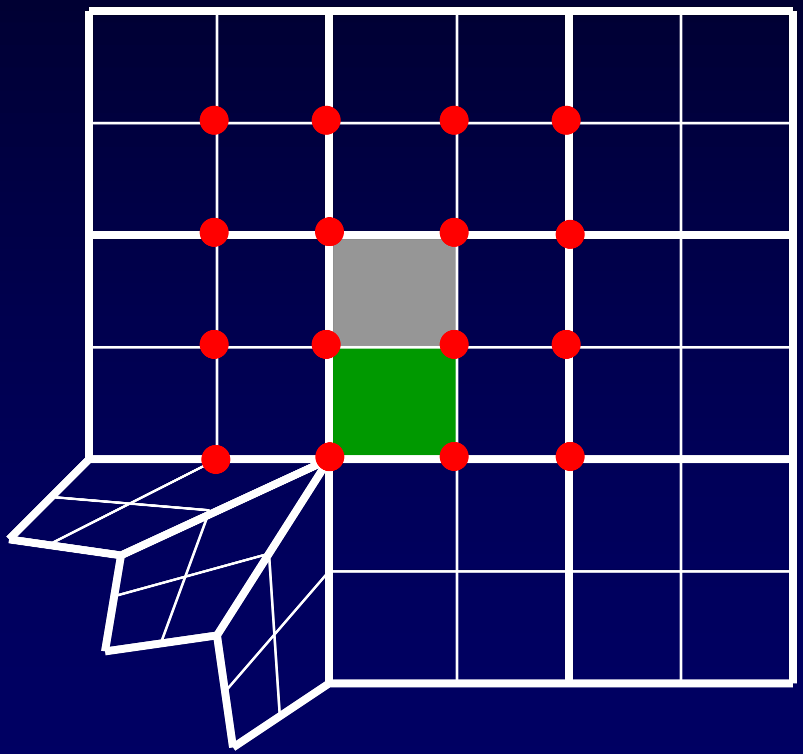

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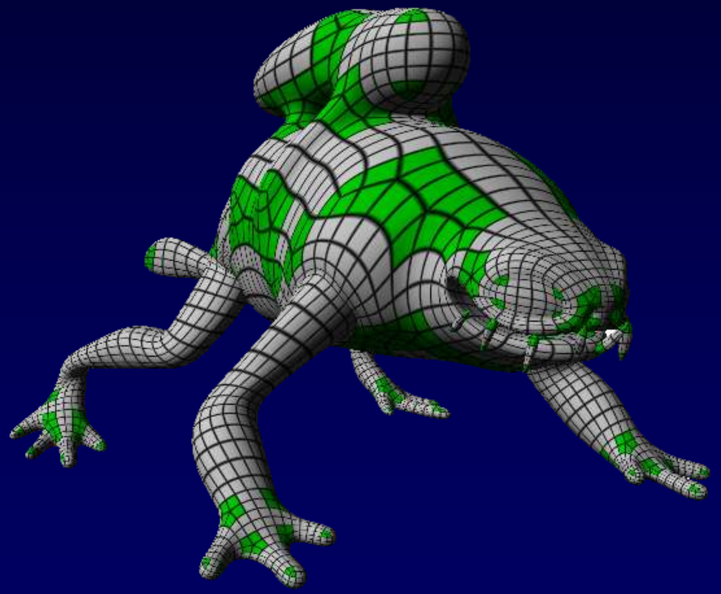

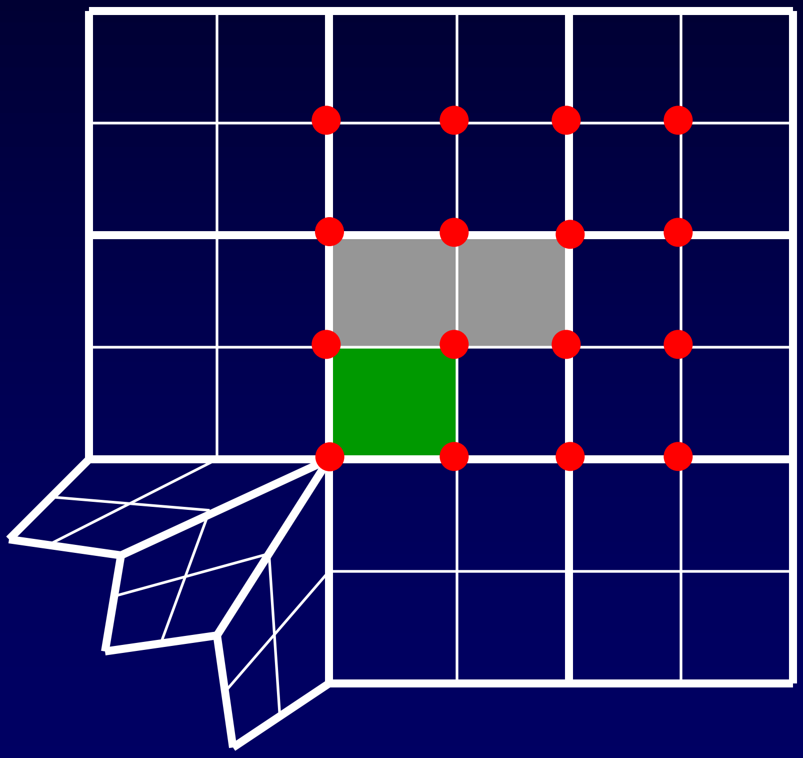

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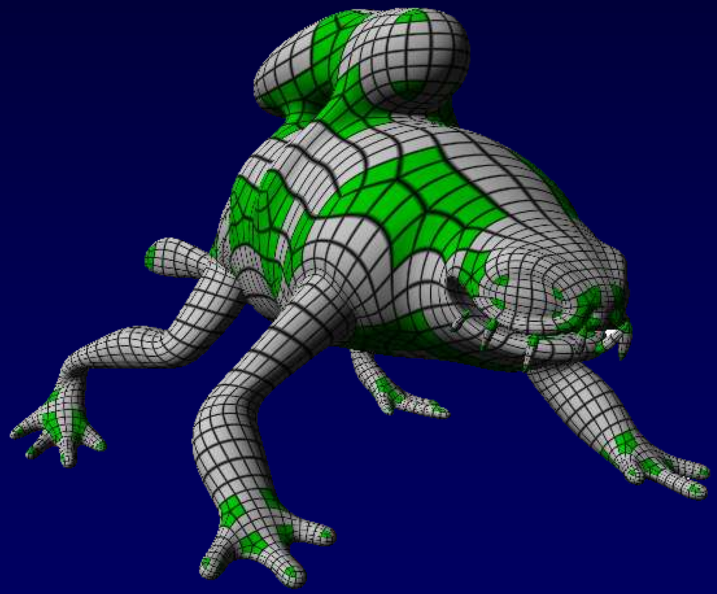

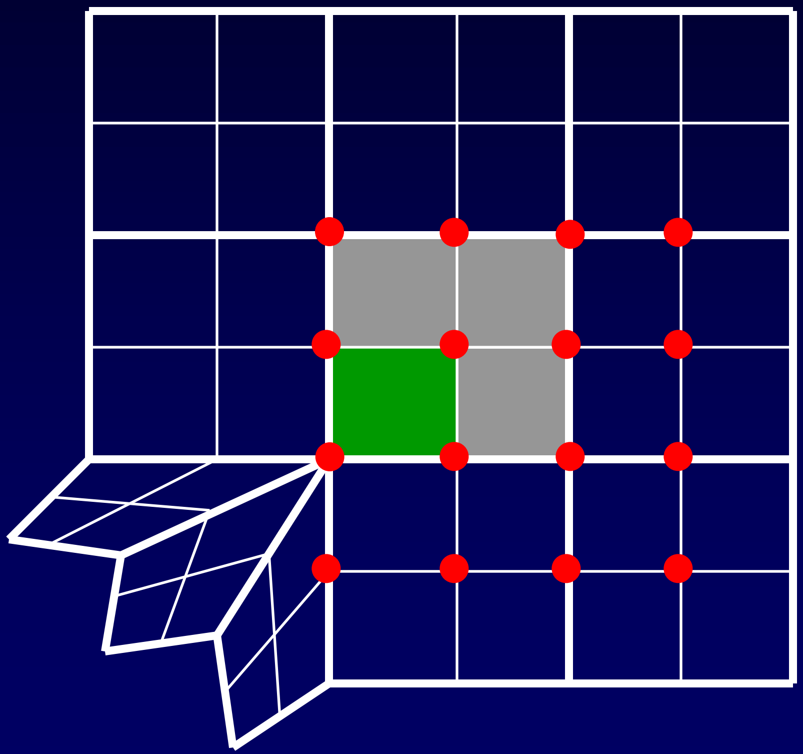

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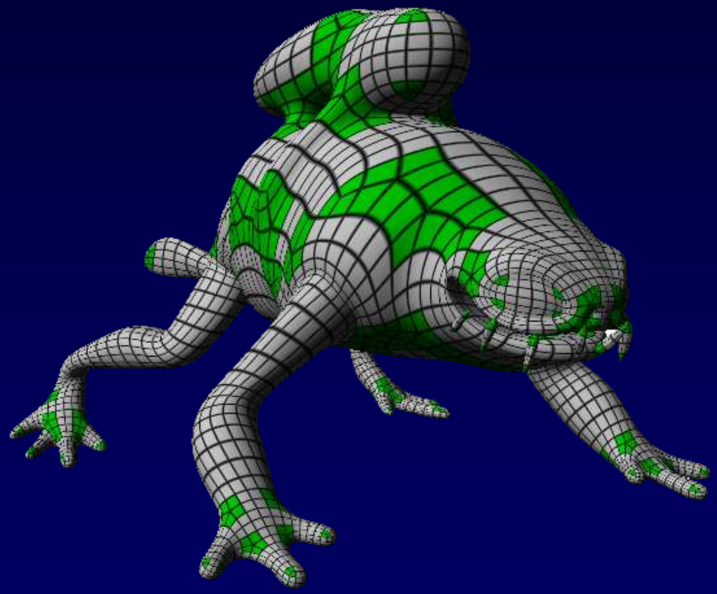

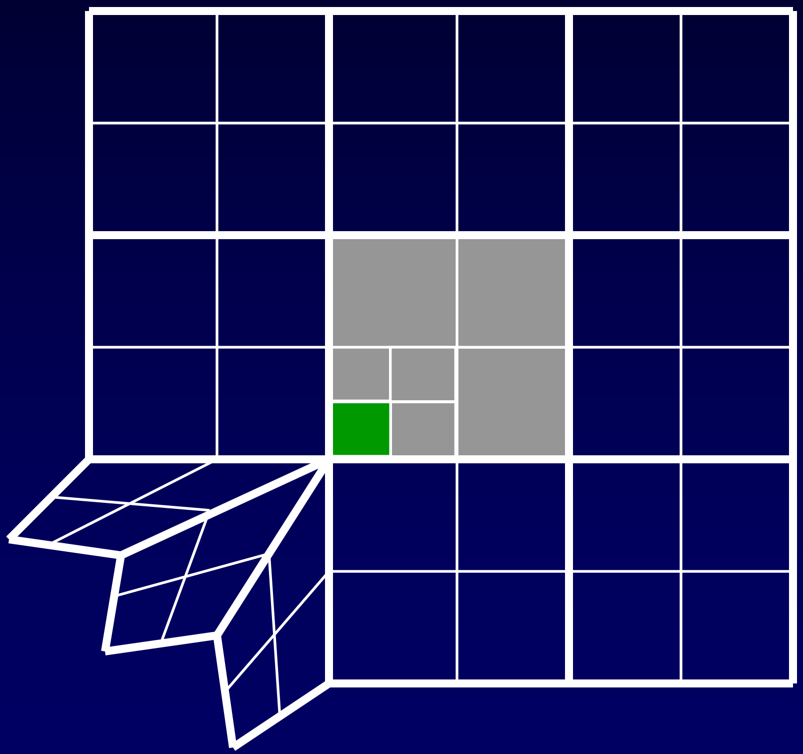

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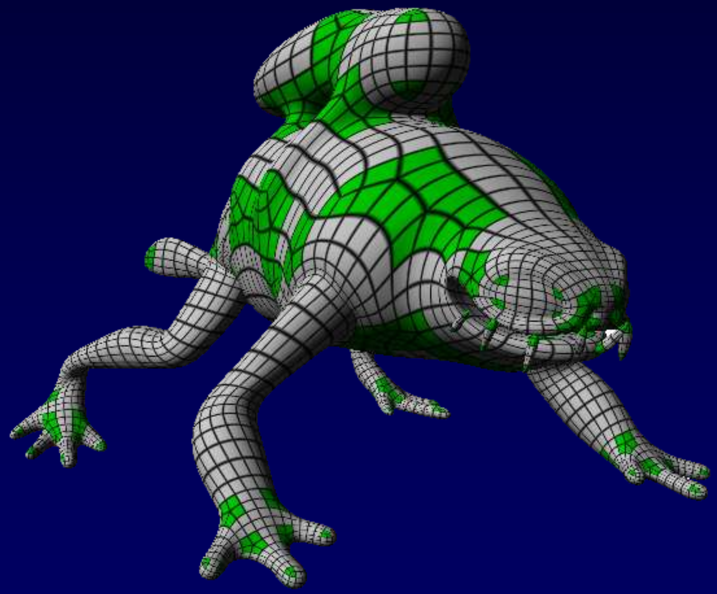
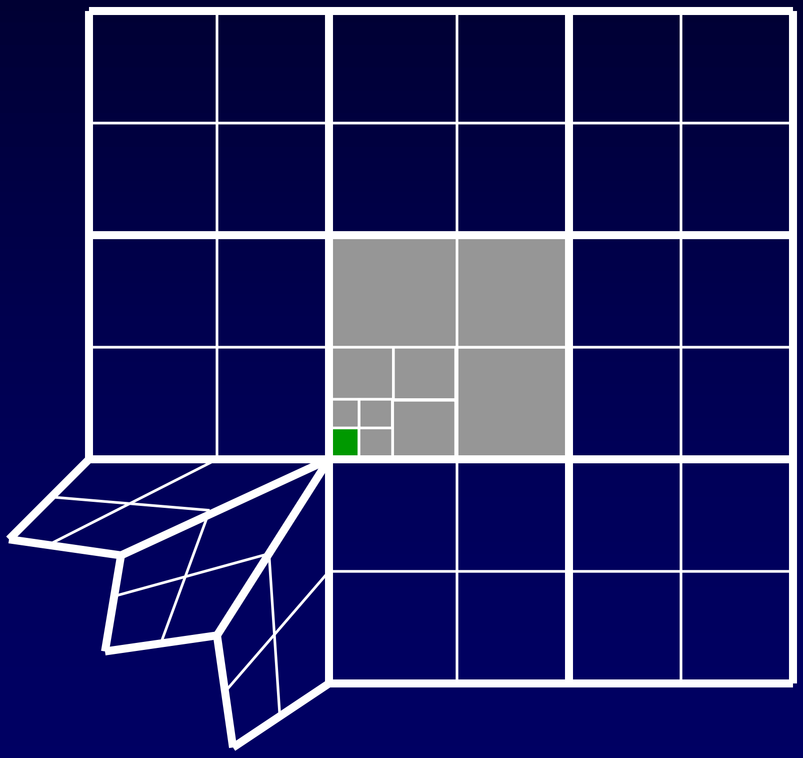
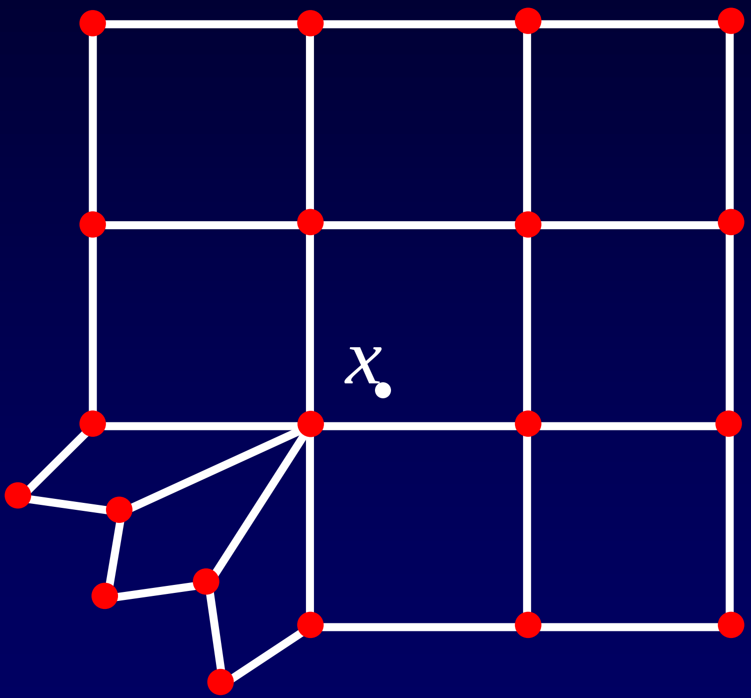




Stam's Exact Evaluation Algorithm

- Subdivide until *x* is in ordinary region

$$S^i P$$



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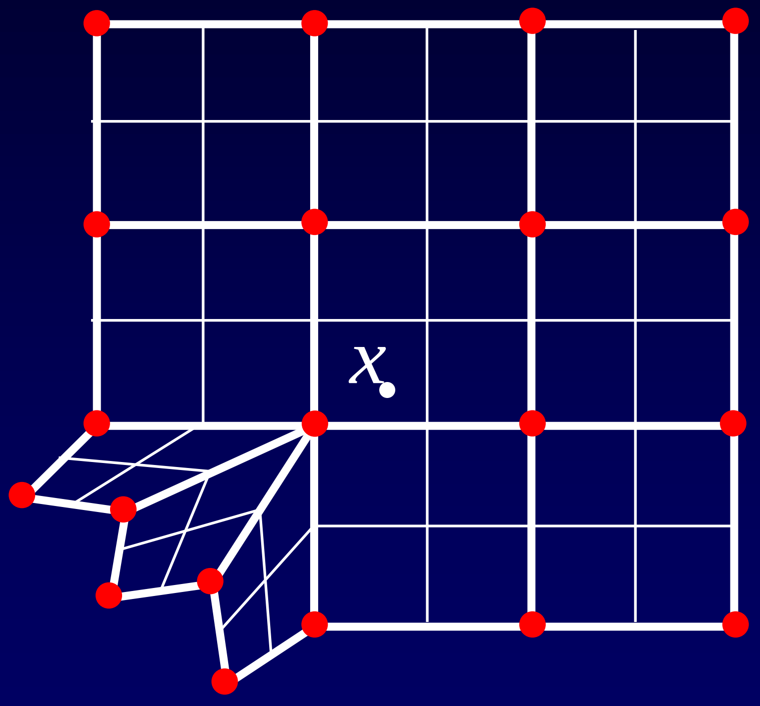

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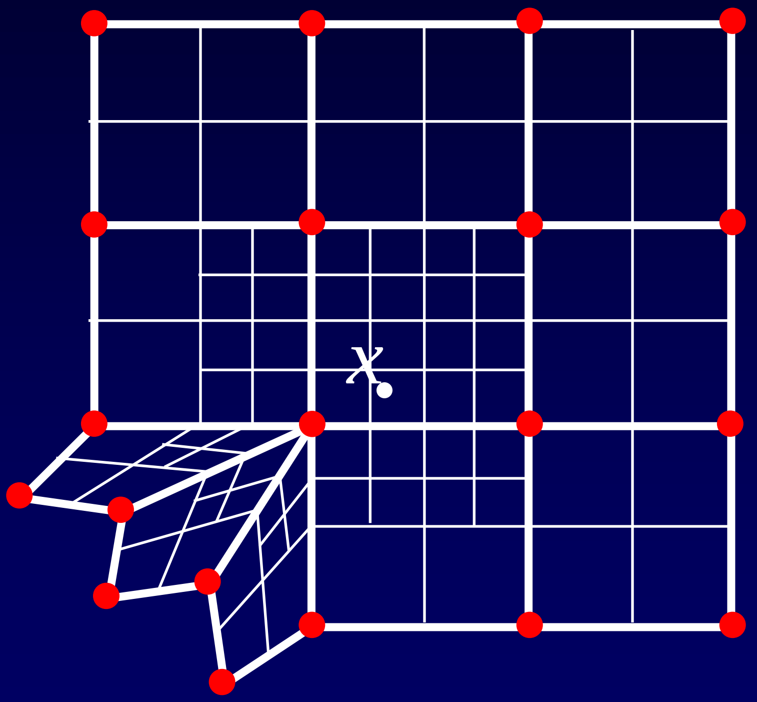
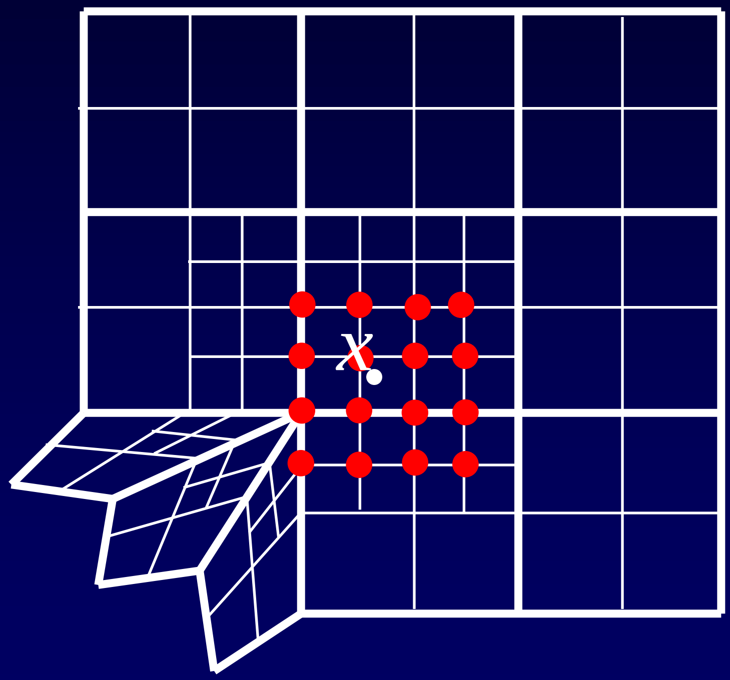


Stam's Exact Evaluation Algorithm

- Subdivide until *x* is in ordinary region

$$S^i P$$

- Extract B-spline control points and evaluate at *x*

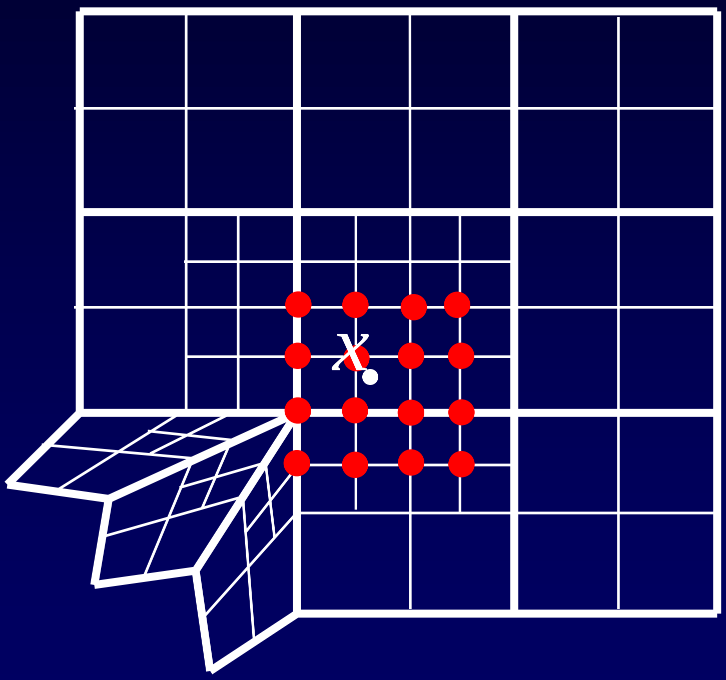


Stam's Exact Evaluation Algorithm

- Subdivide until *x* is in ordinary region

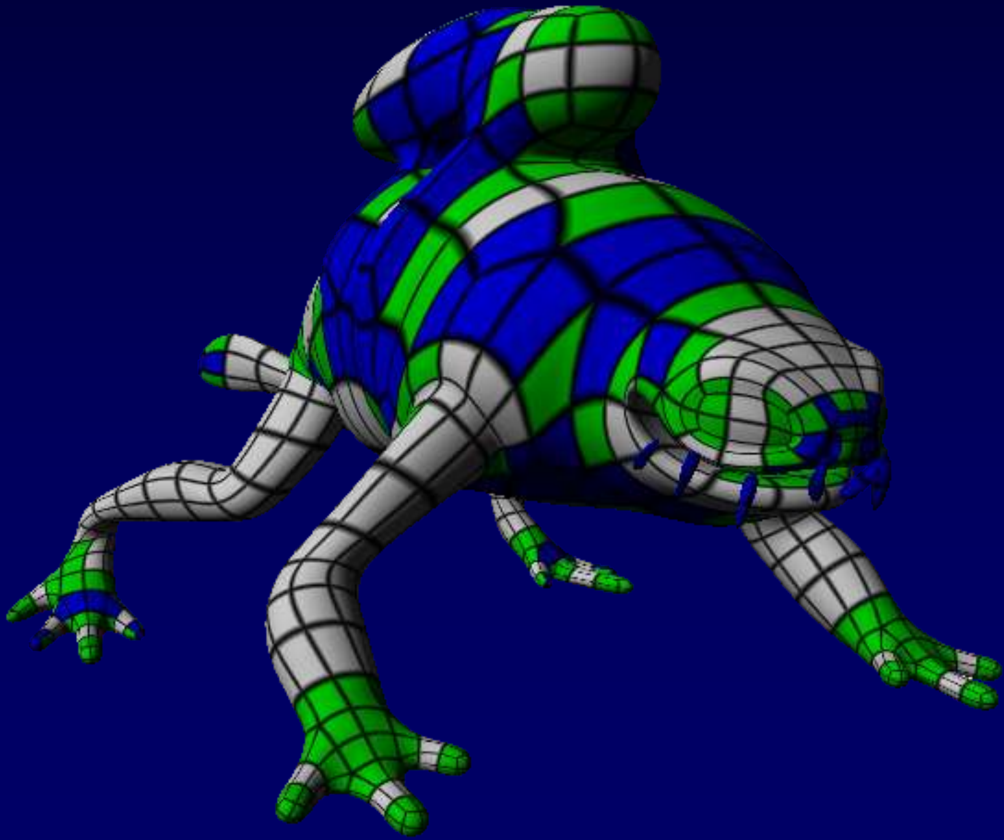
$$V\Lambda^i V^{-1}P$$

- Extract B-spline control points and evaluate at *x*



Performance Issues

- Limits # extraordinary verts



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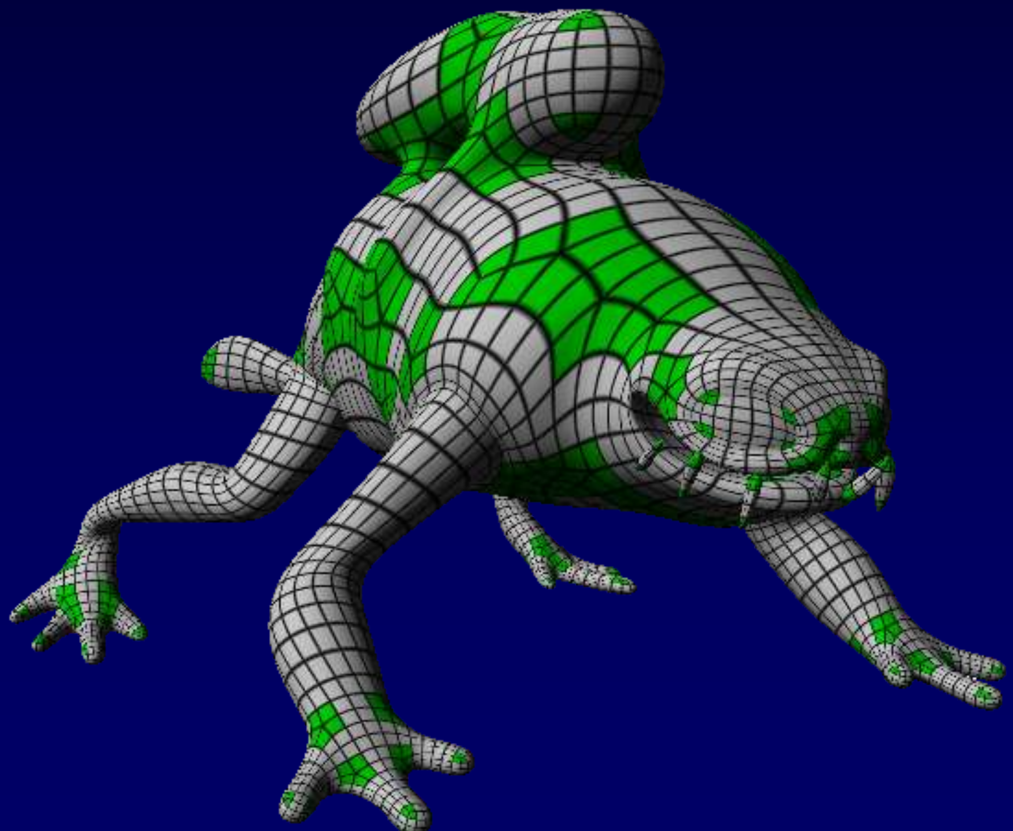
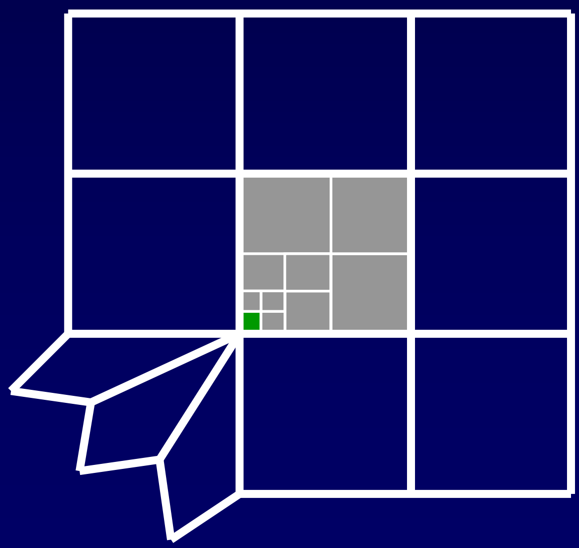


Performance Issues

- Limits # extraordinary verts
- Lots of shader constants

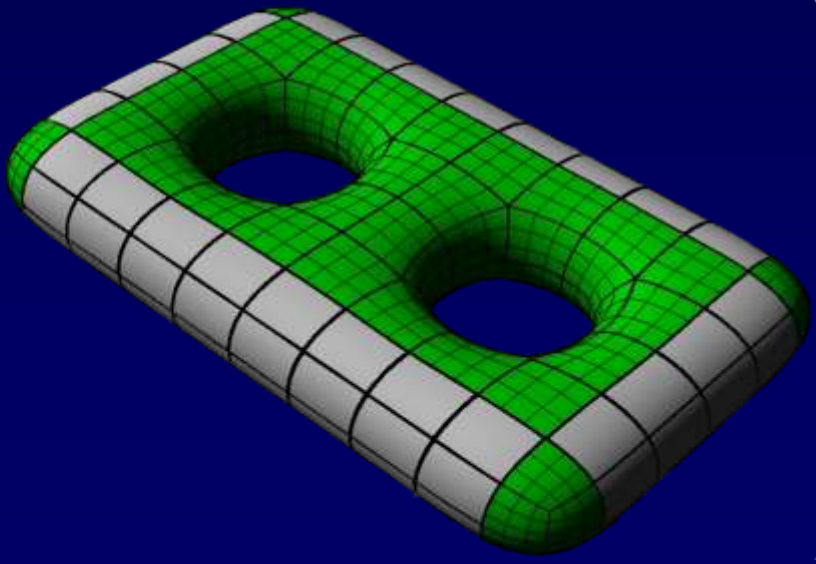
$$V\Lambda^i(V^{-1}P)$$



Valence	Constants
3	882
4	1040
5	1206
6	1380
7	1562
8	1752

Solution: Polynomial Patches

- Replace extraordinary patches with polynomials
  - Geometry patch (degree 3x3)
  - 2 Tangent patches (degree 3x2)
- Based on conversion from B-spline to Bezier form



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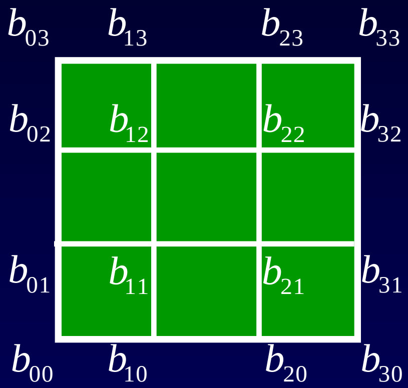

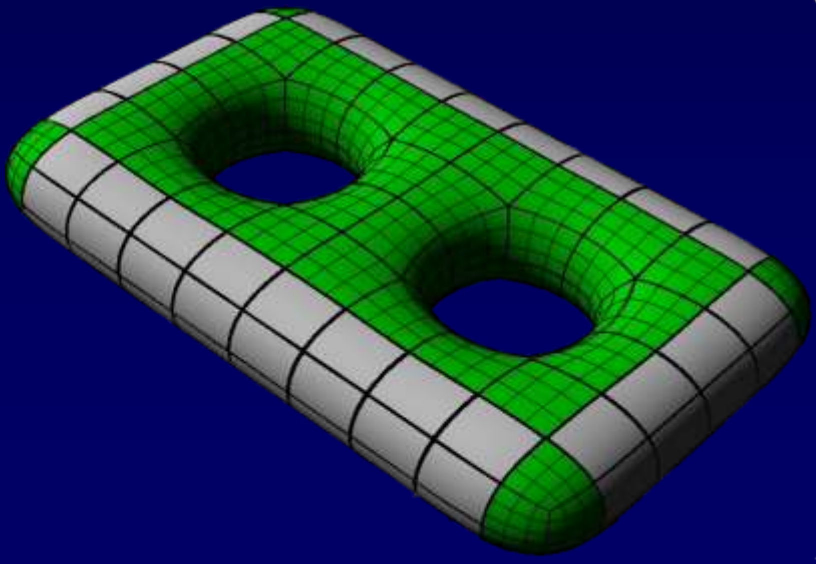

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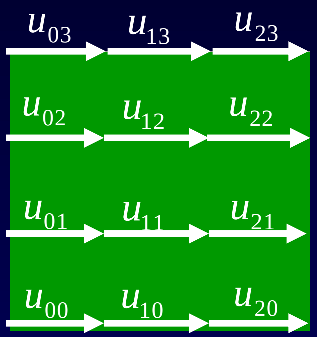

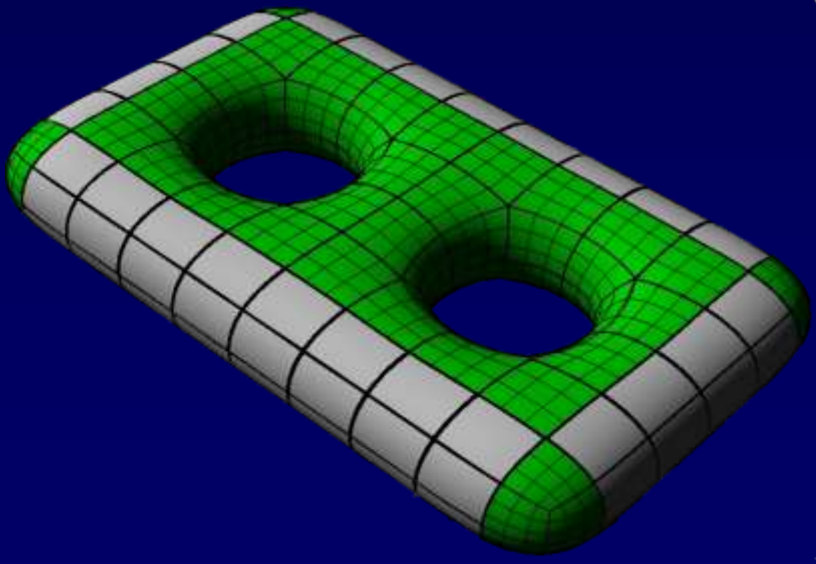

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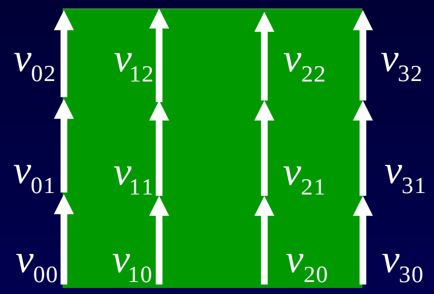
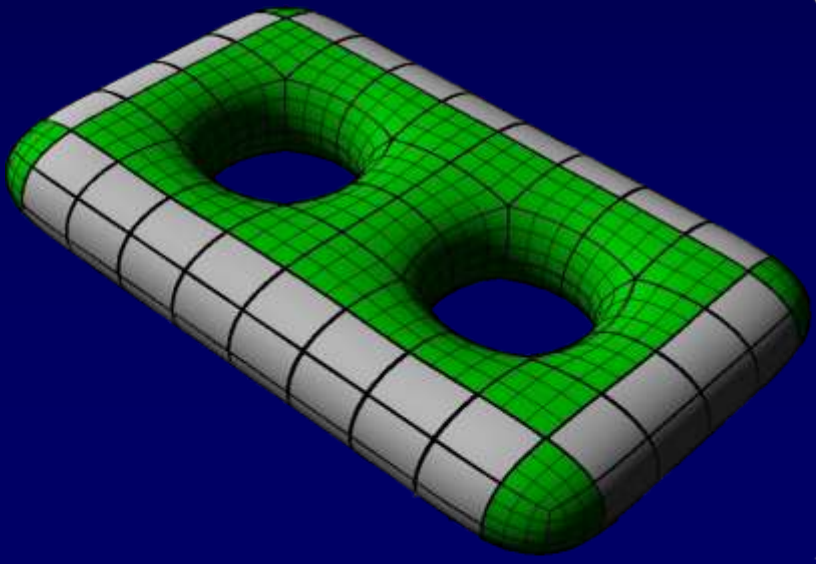
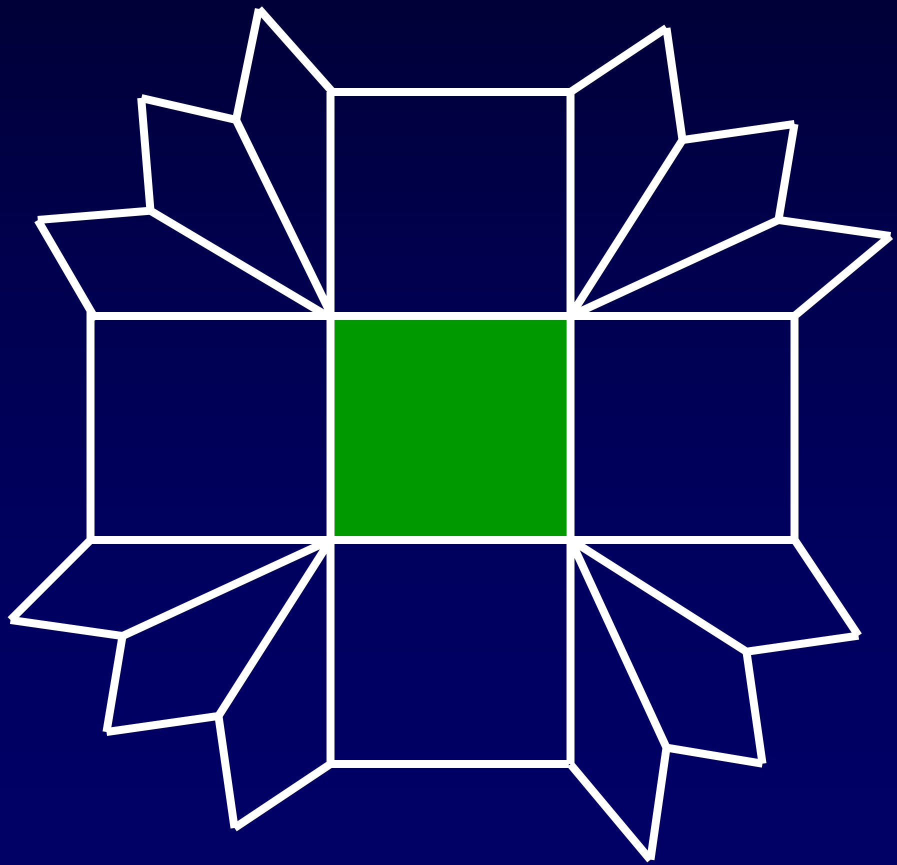




ACC Geometry Patches

- Use knot-insertion rules from ordinary case
- At corners, use limit masks



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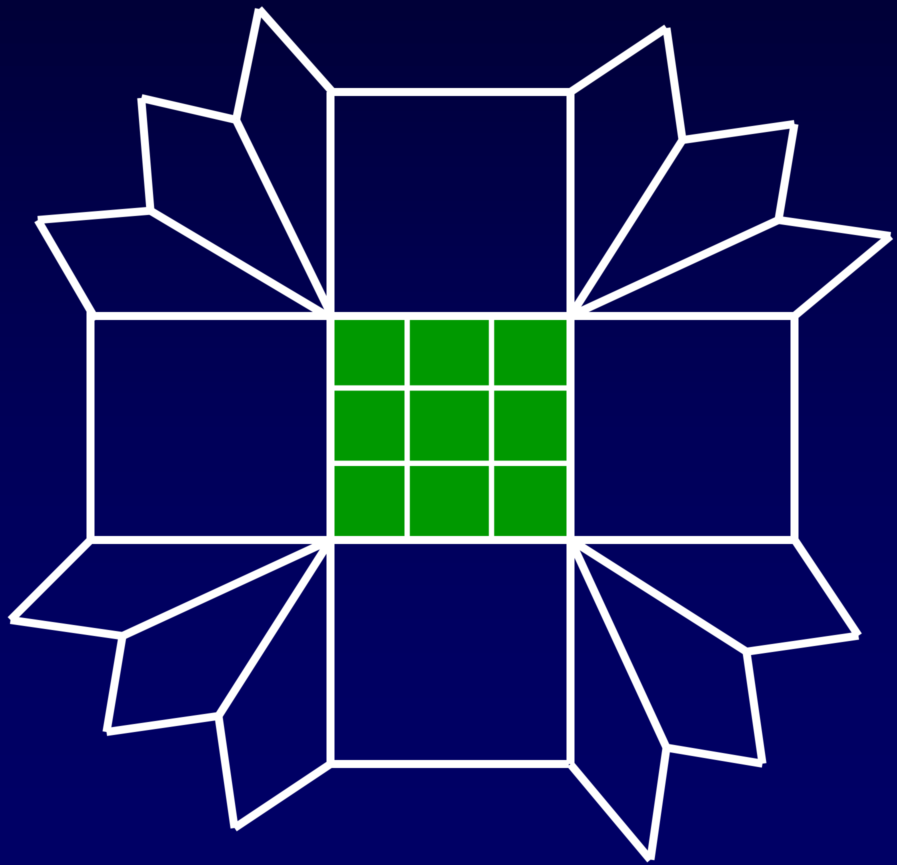

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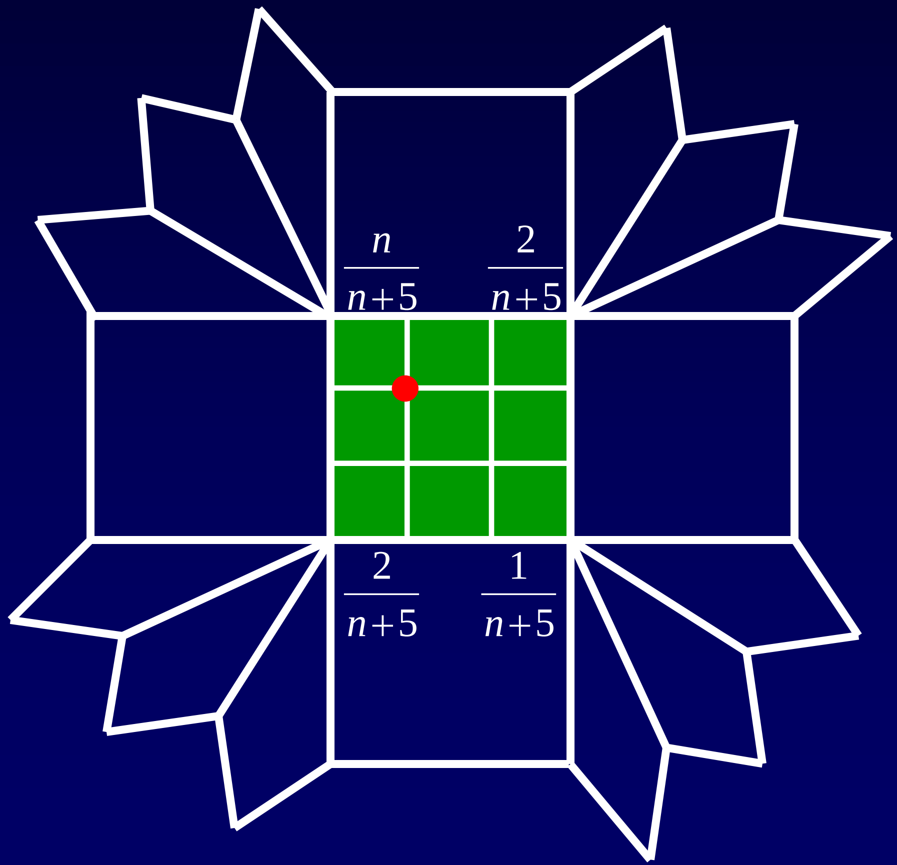

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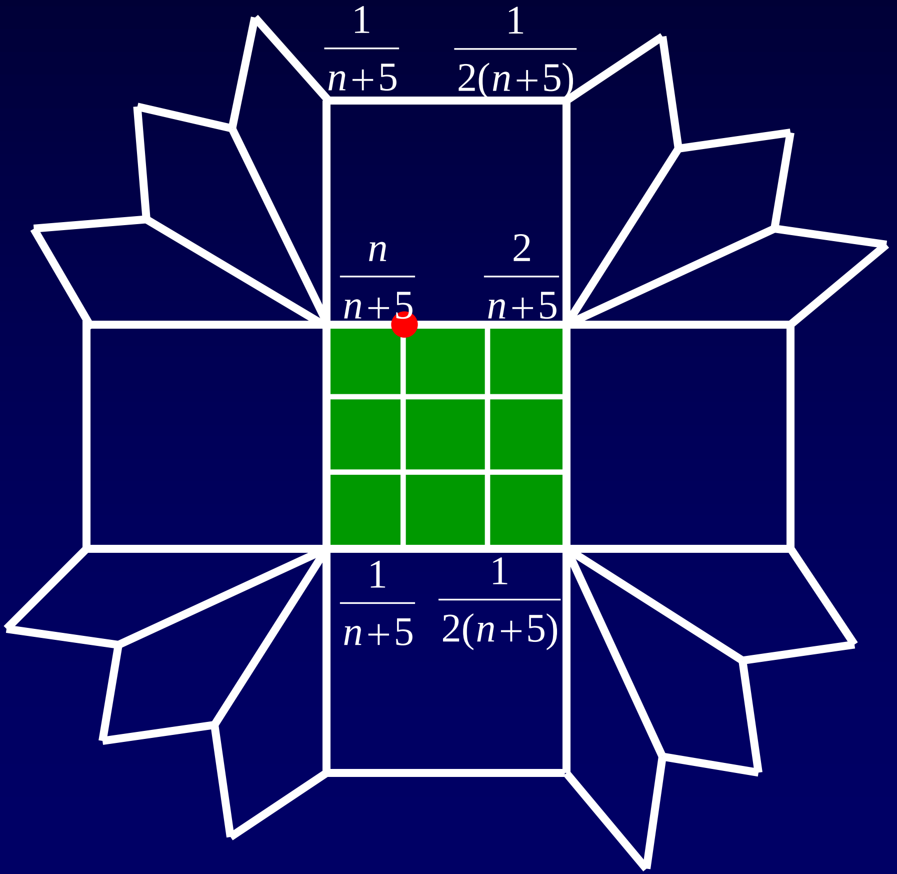

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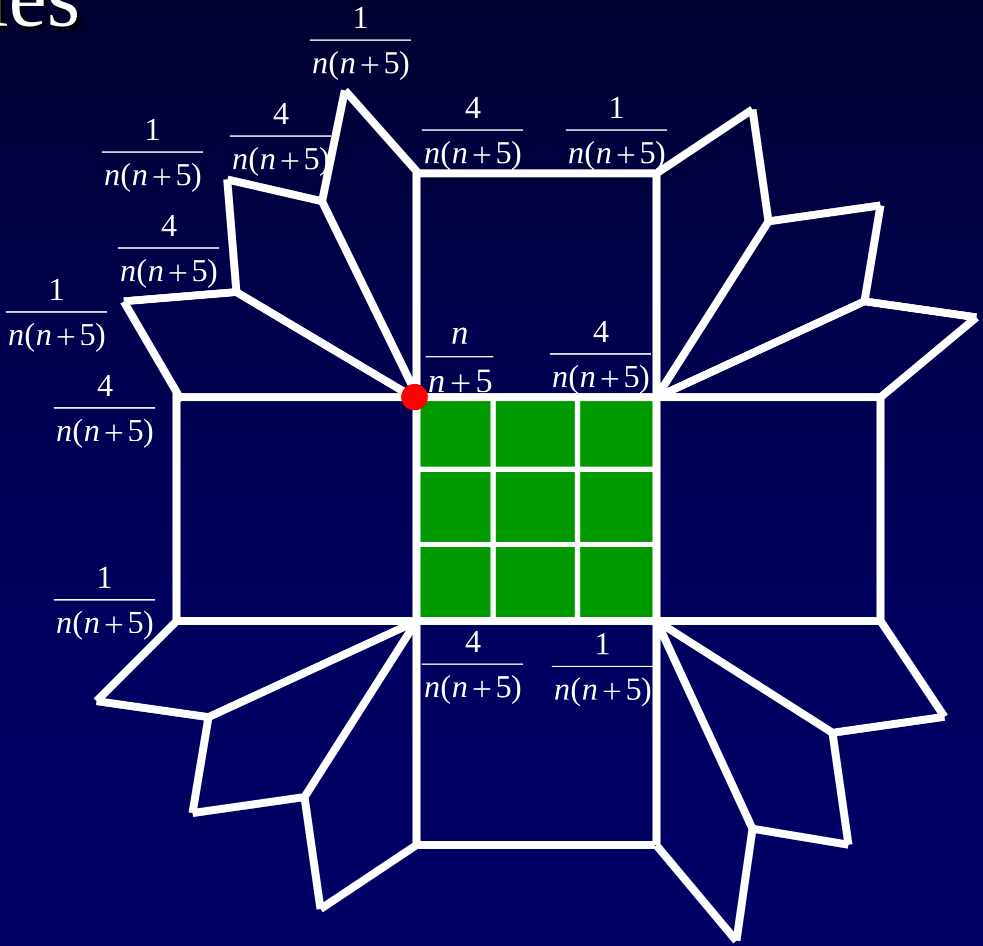
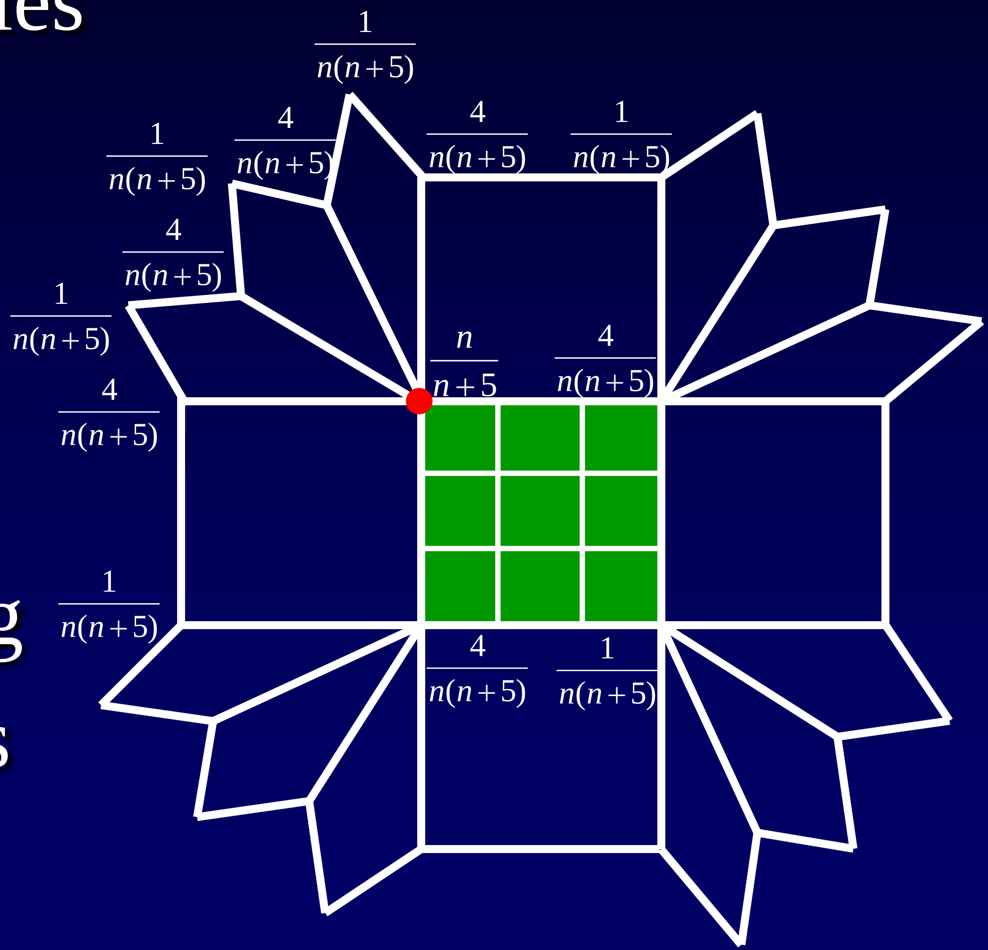


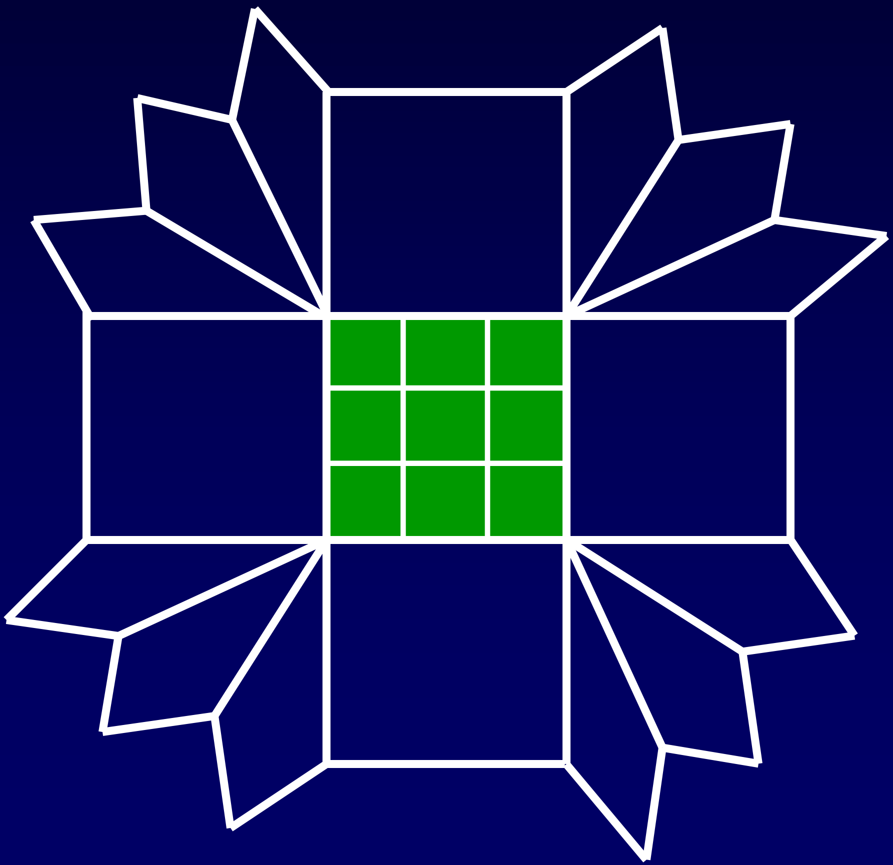
ACC Geometry Patches

- Use knot-insertion rules from ordinary case
- At corners, use limit masks
- Smooth everywhere except edges touching extraordinary vertices



ACC Tangent Patches

- Continuous normal field needed for displacement mapping
- Create two tangent patches (*u*/*v*) for each position patch



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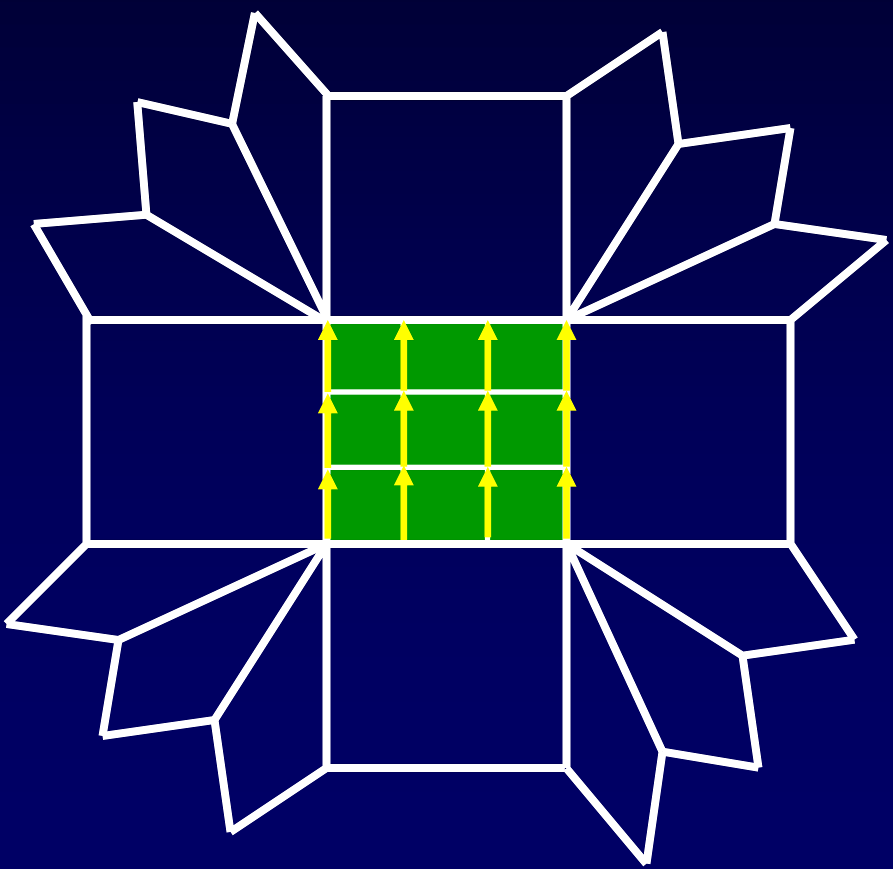

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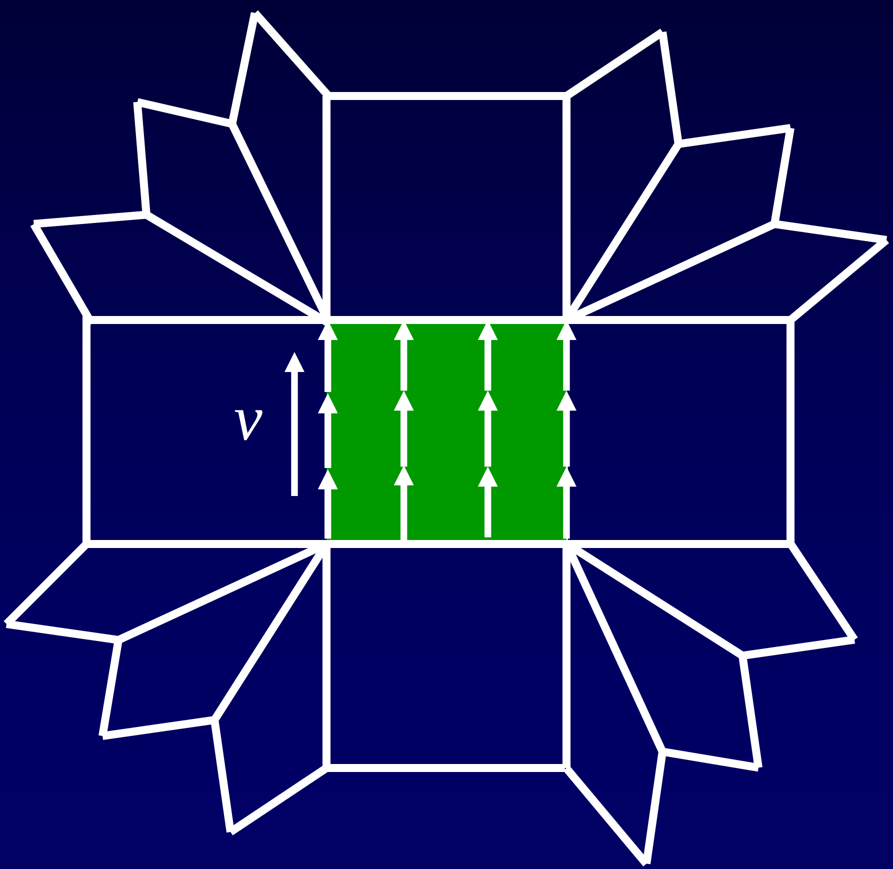

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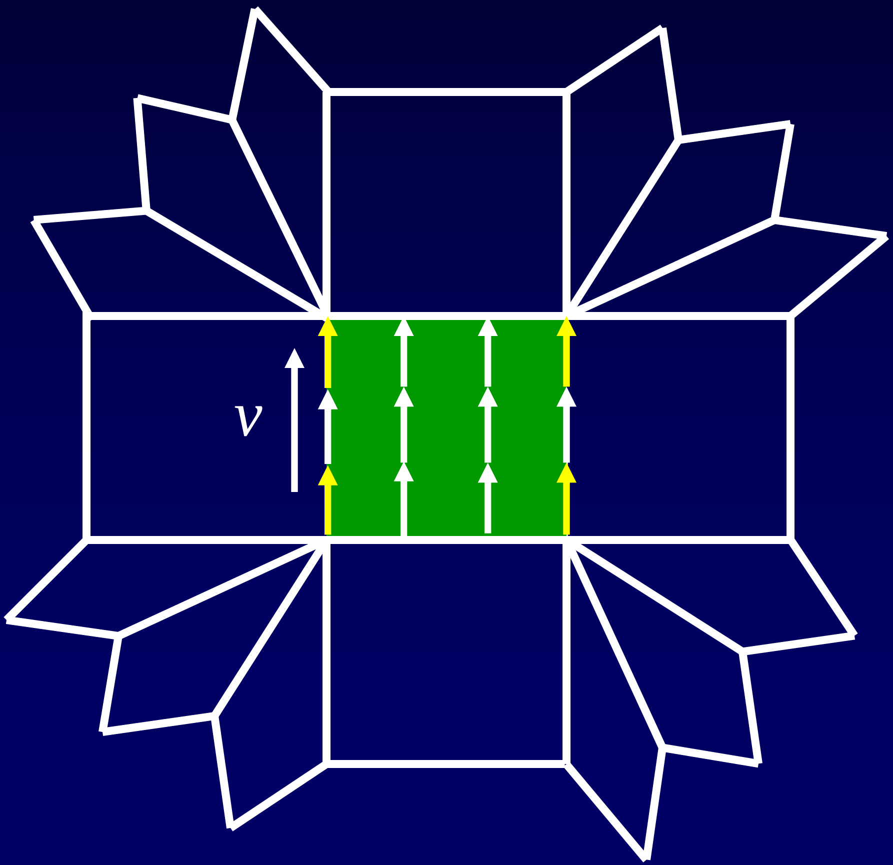

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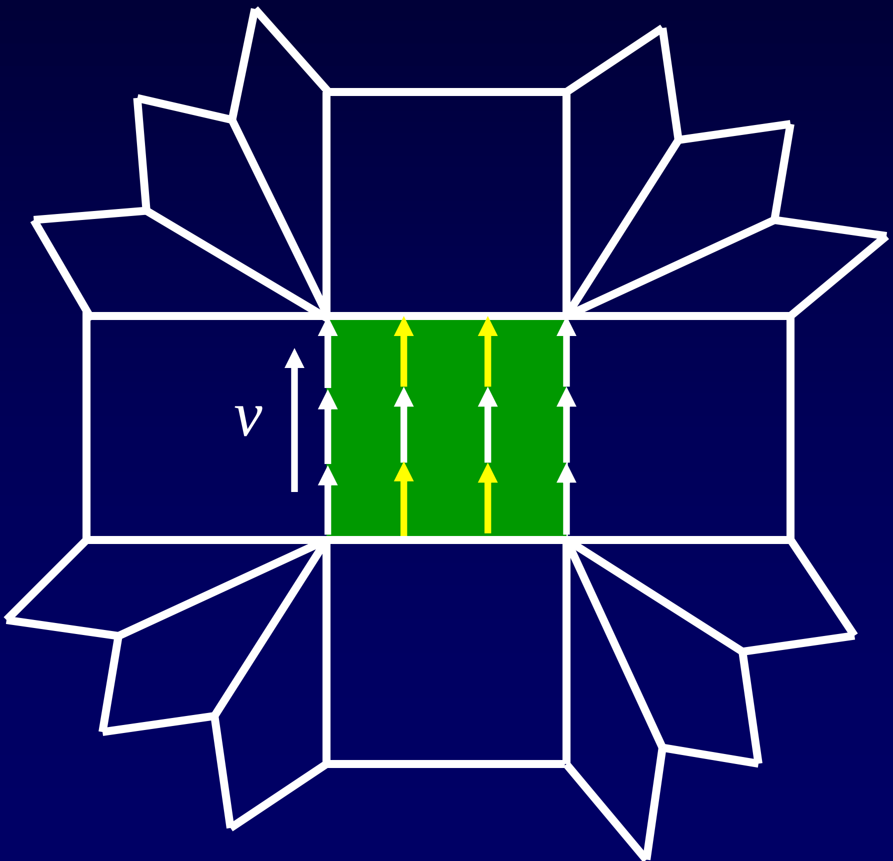

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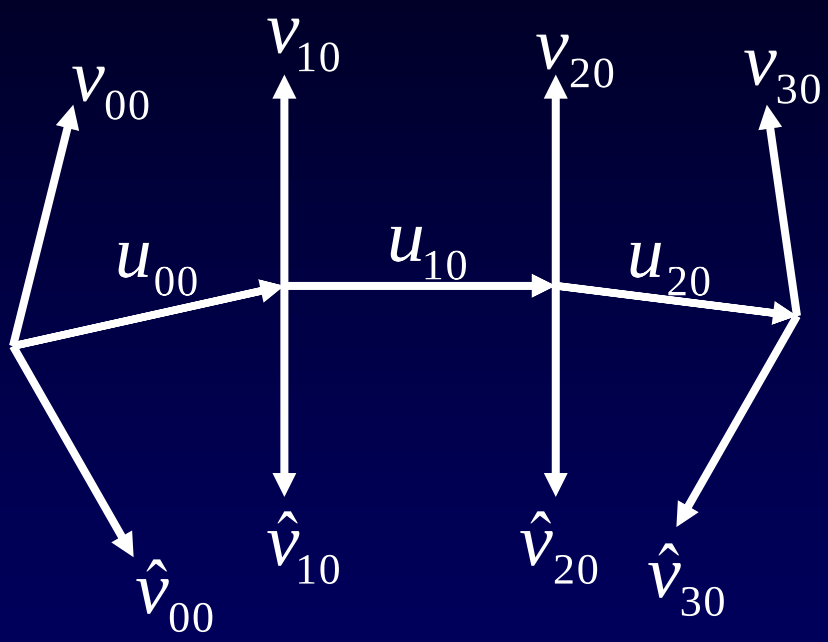
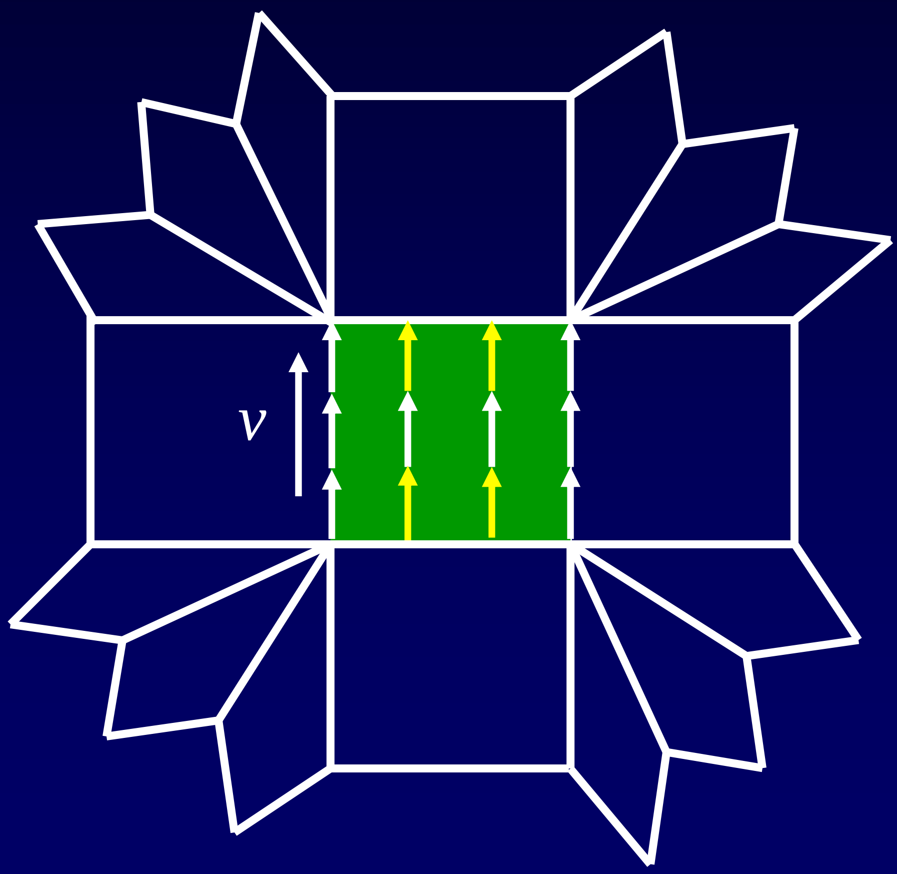
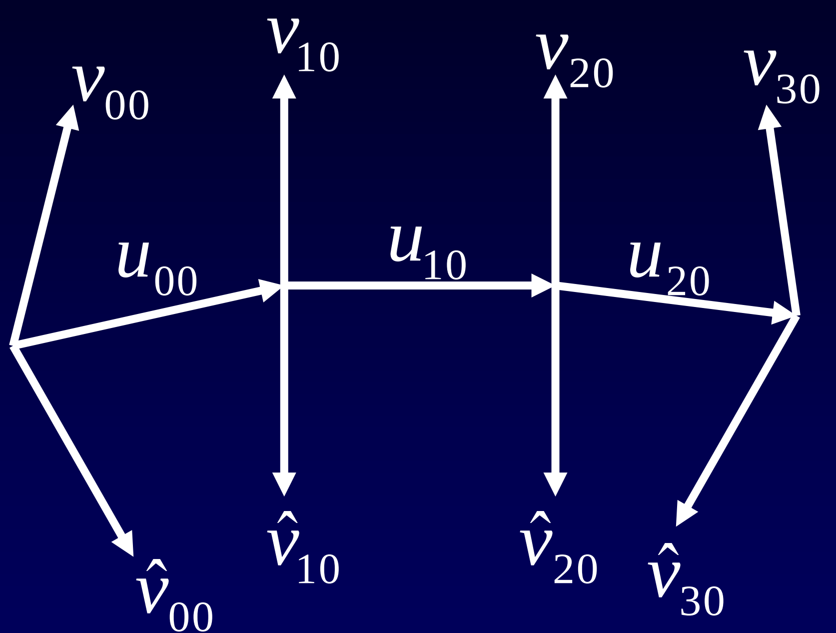


$$v(t)\times u(t)\propto \hat{v}(t)\times u(t)$$



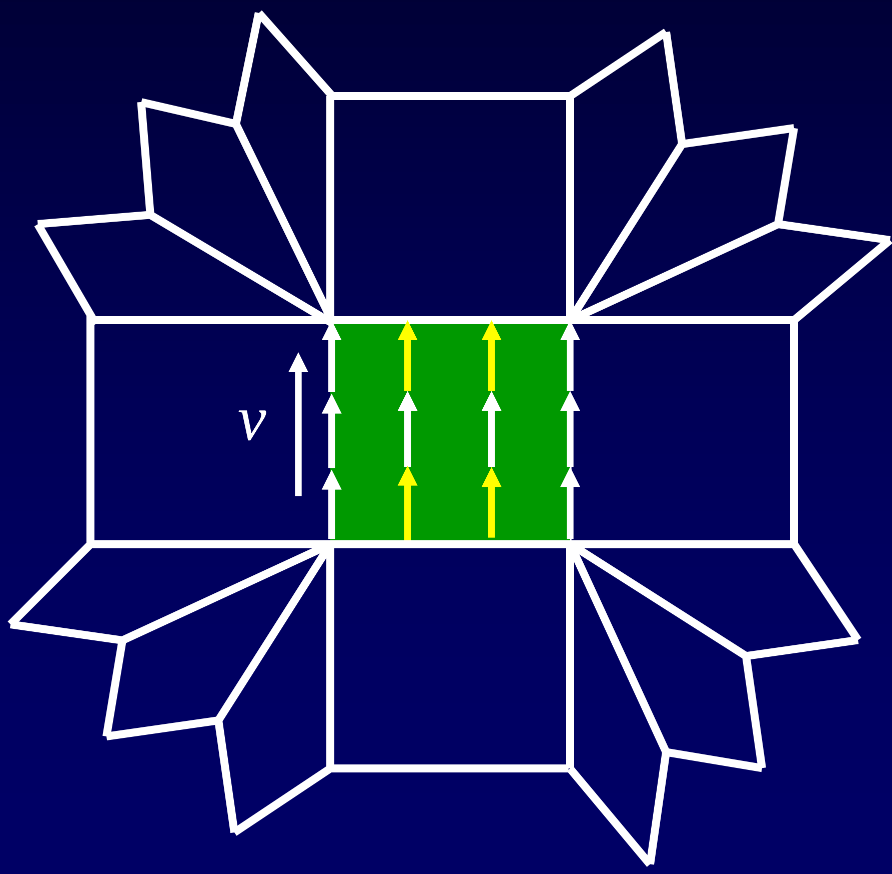
ACC Tangent Patches



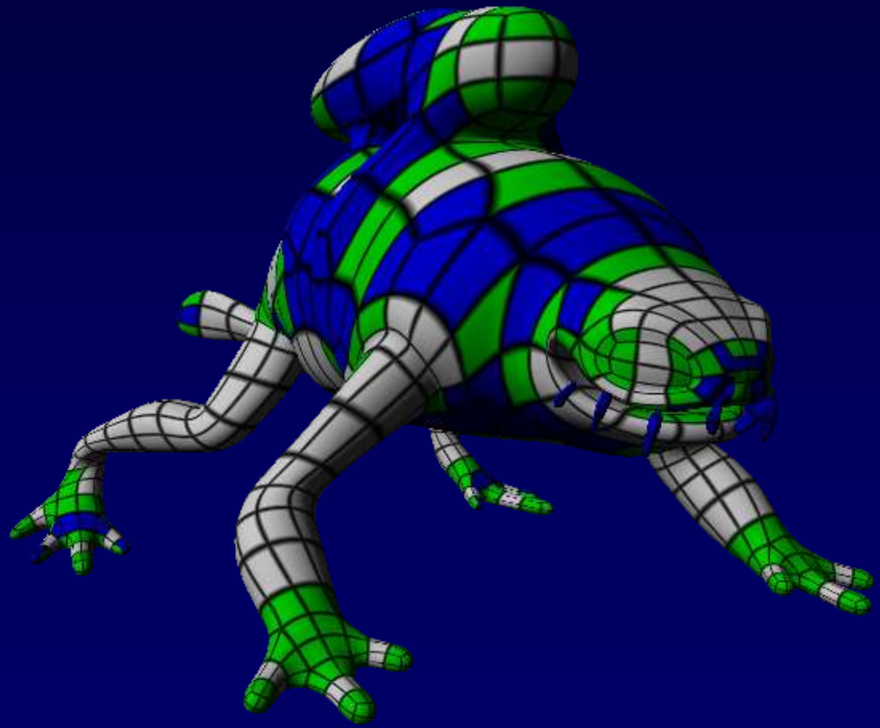
$$v_{10} += \tfrac{2}{3} c_0 u_{10} - \tfrac{1}{3} c_1 u_{00}$$

$$v_{20} += \tfrac{1}{3} c_0 u_{20} - \tfrac{2}{3} c_1 u_{10}$$

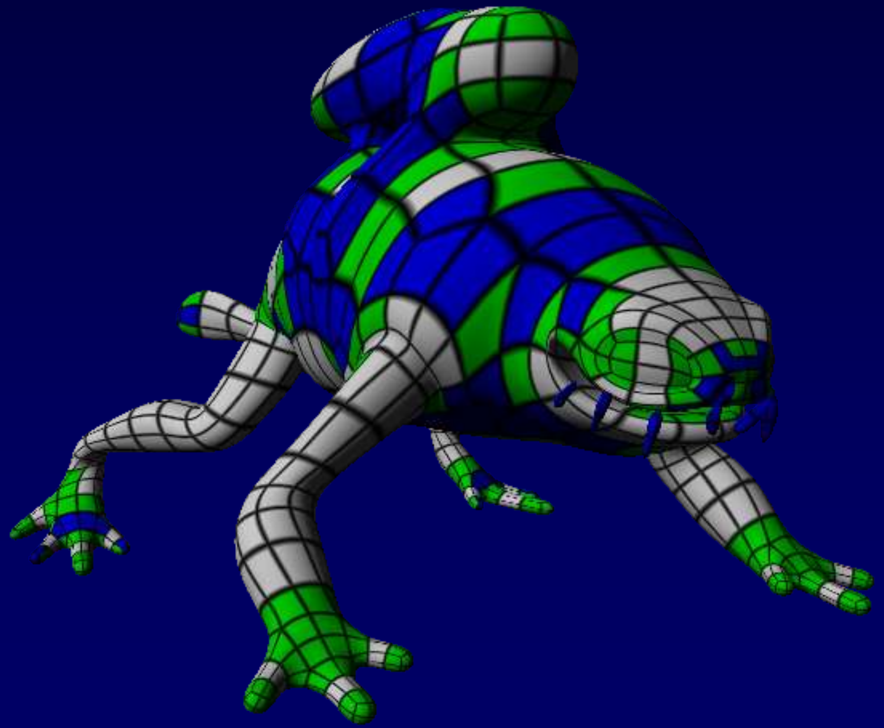
$$c_i = \cos\left(\frac{2\pi}{n_i}\right)$$

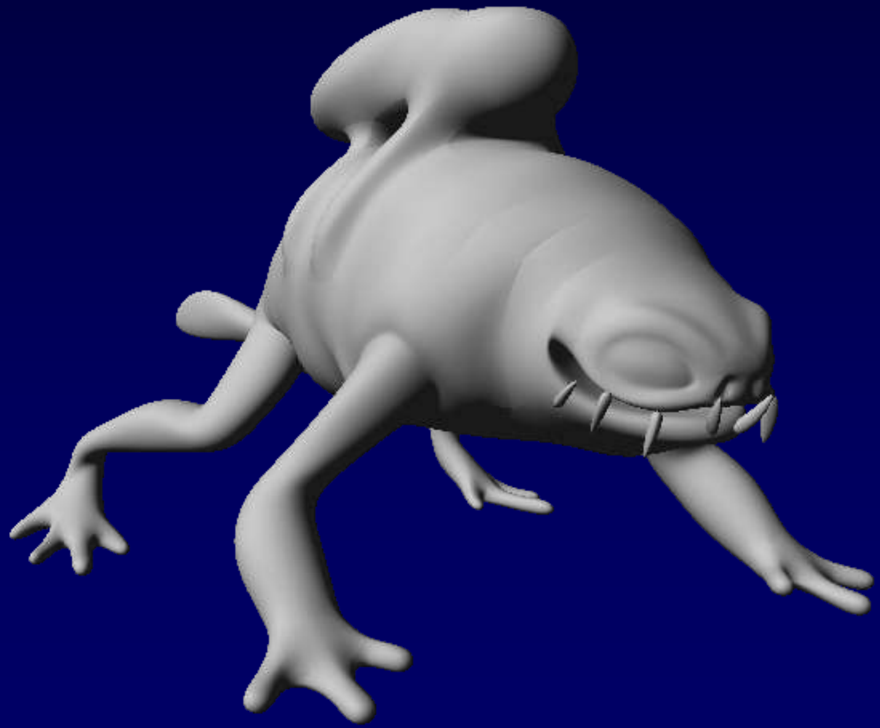


Examples



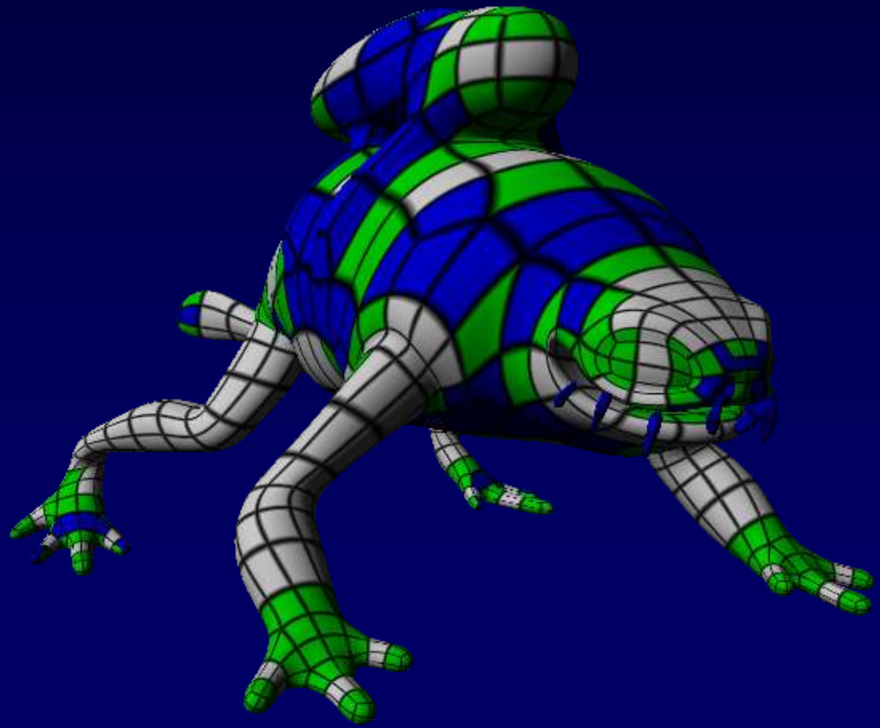
Examples

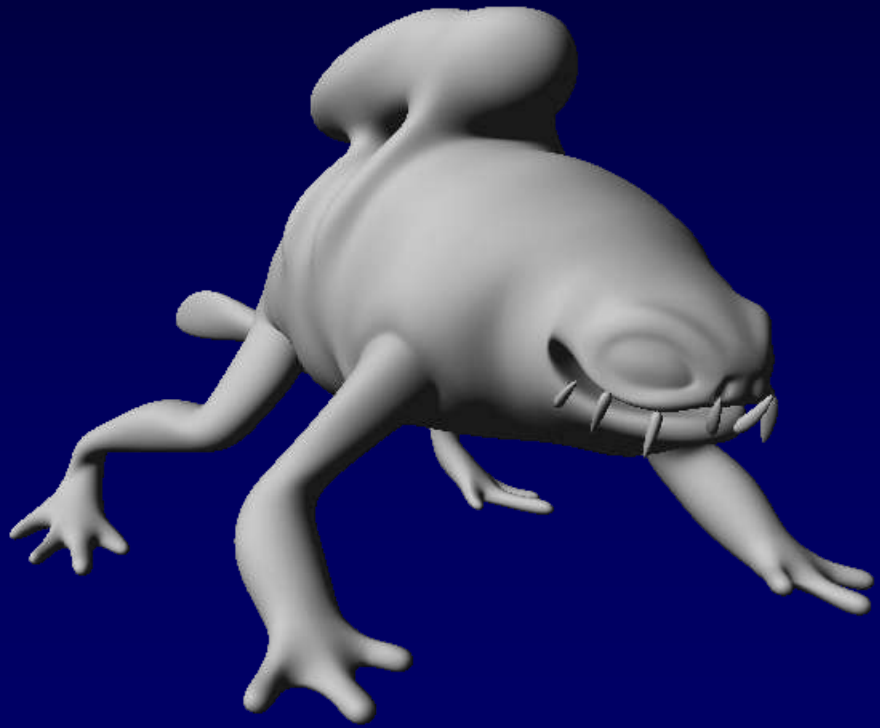




ACC Geometry Patches

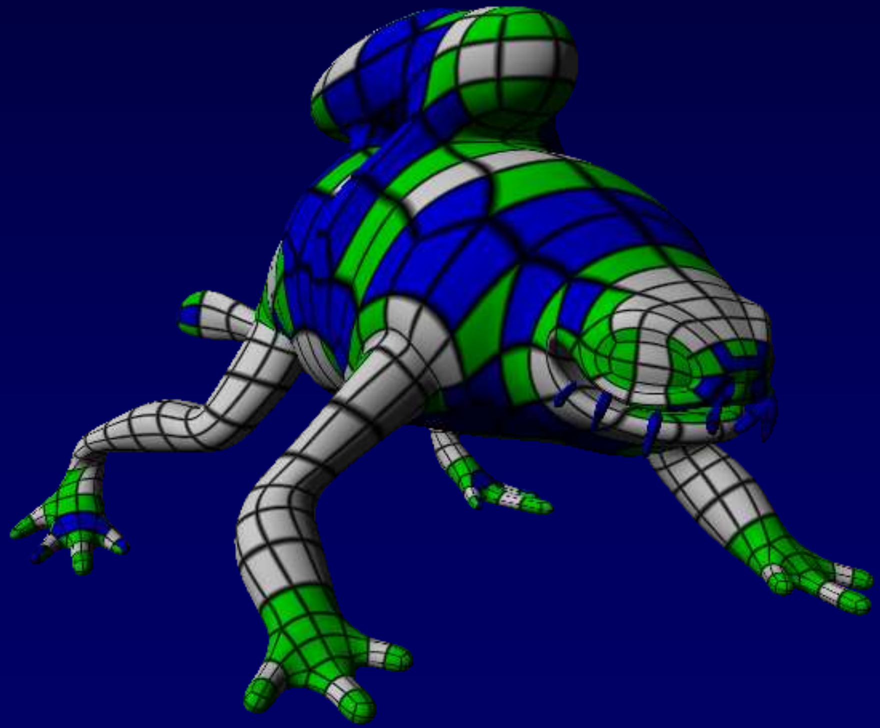
Examples

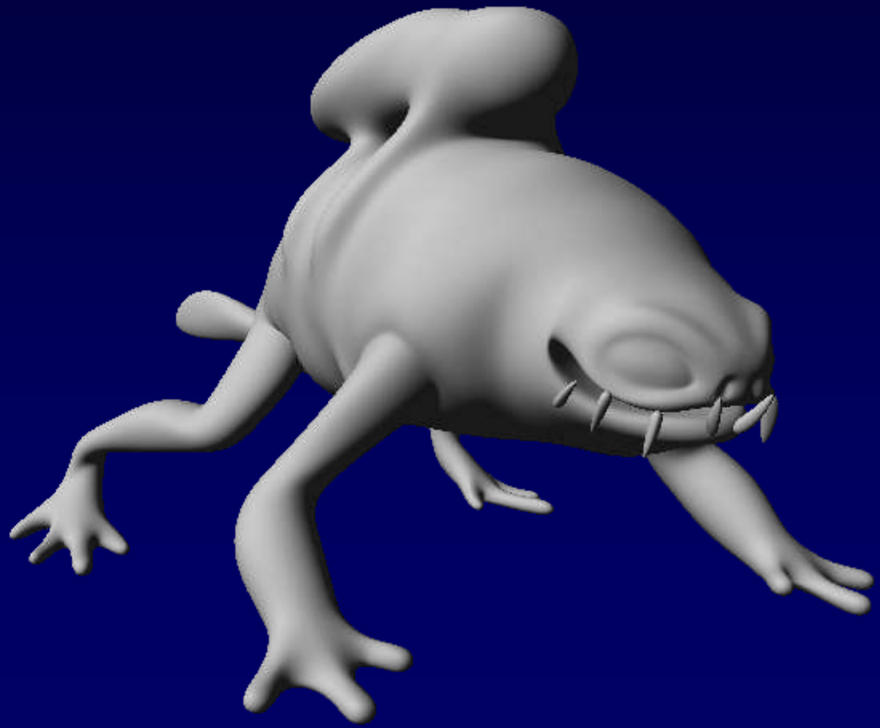




ACC Geo/Tan Patches

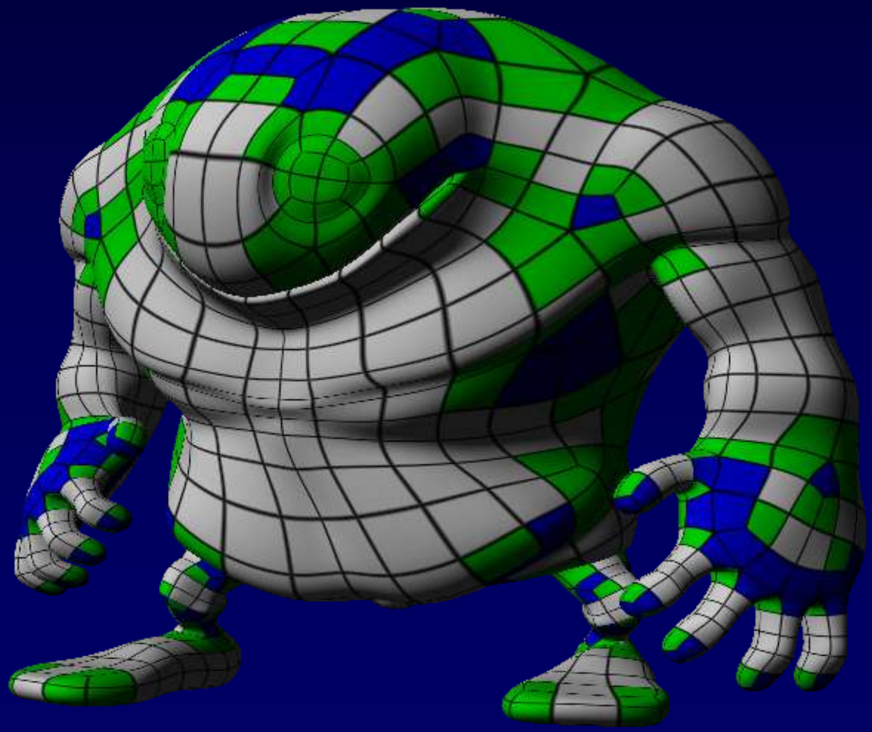
Examples



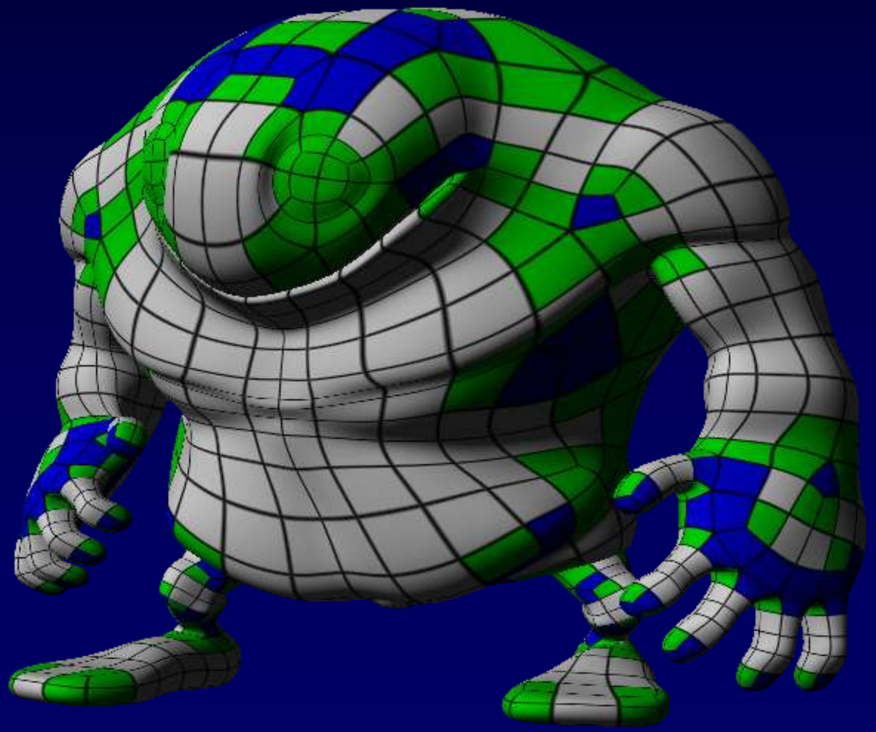
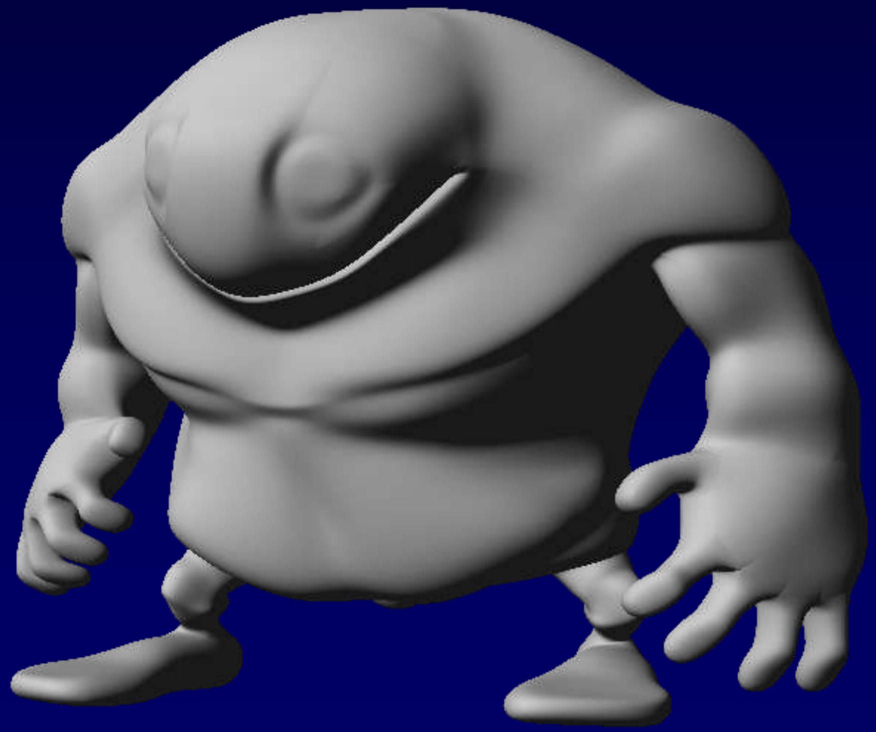


Catmull-Clark Surface

Examples

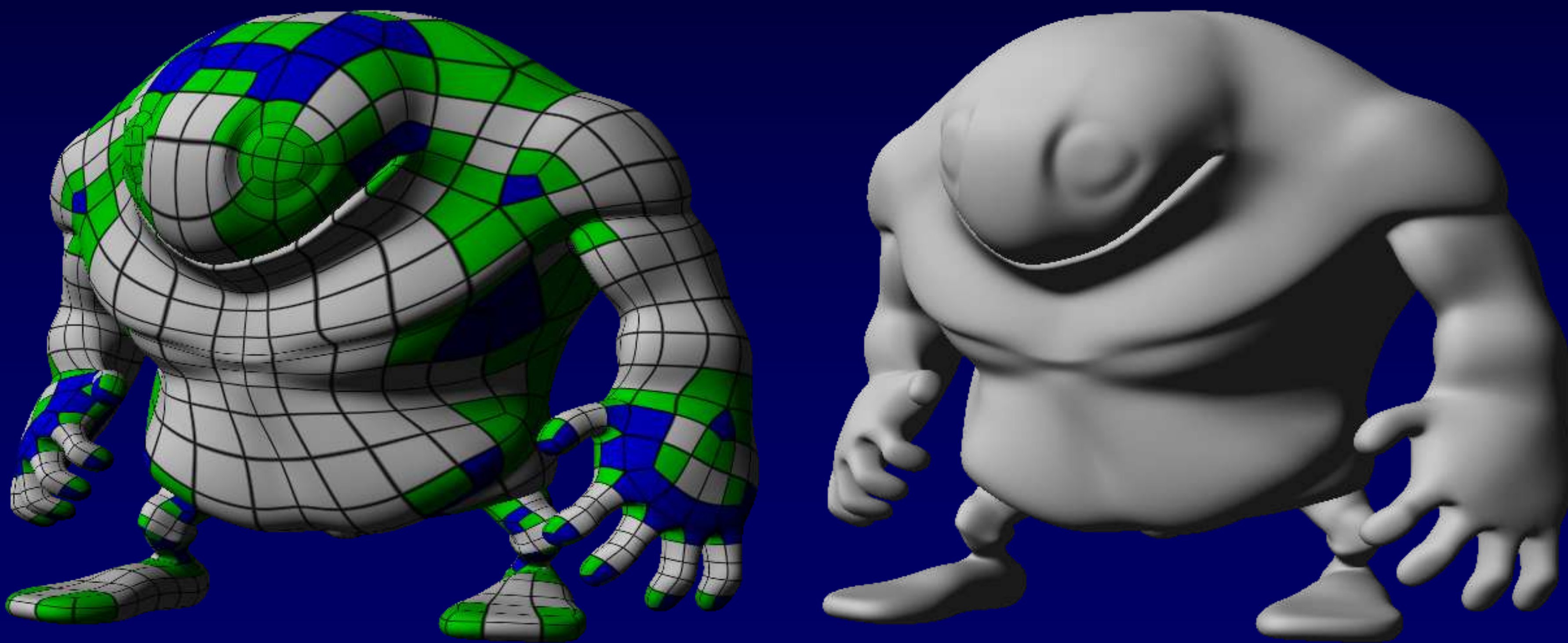


Examples

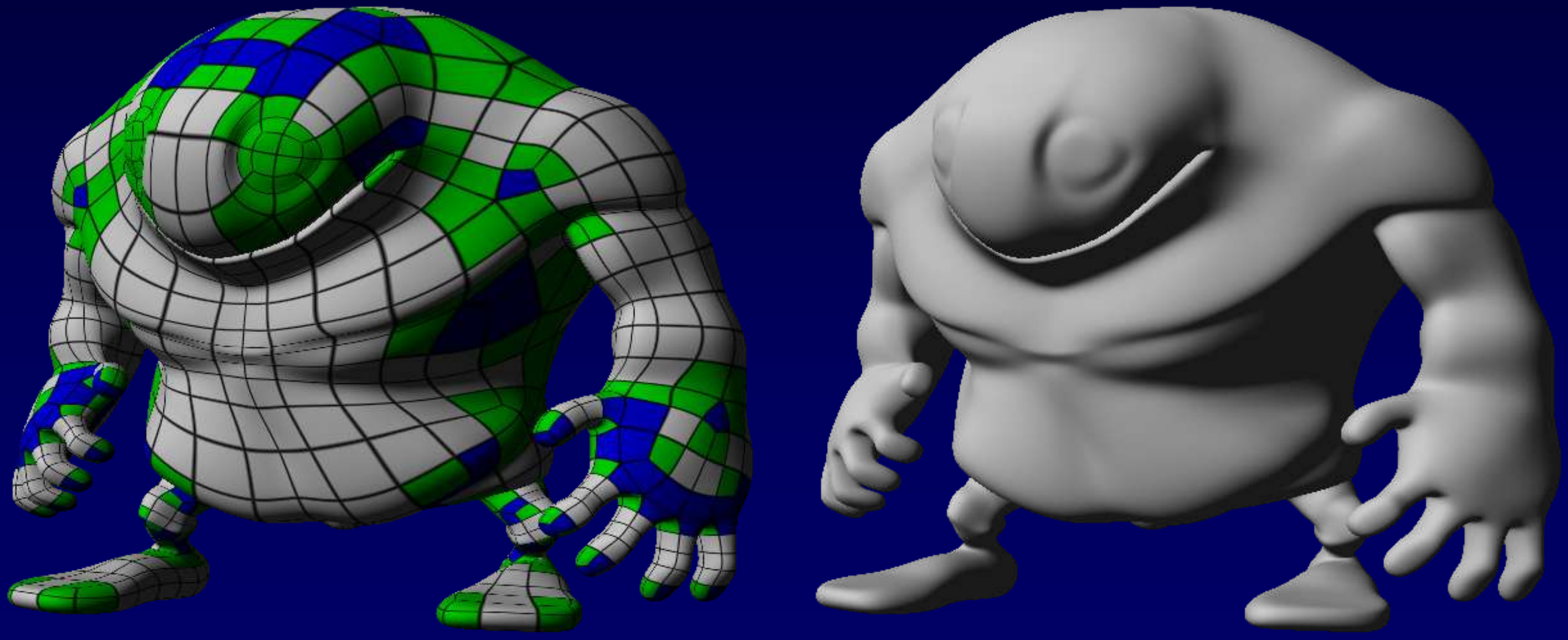
ACC Geometry Patches

Examples



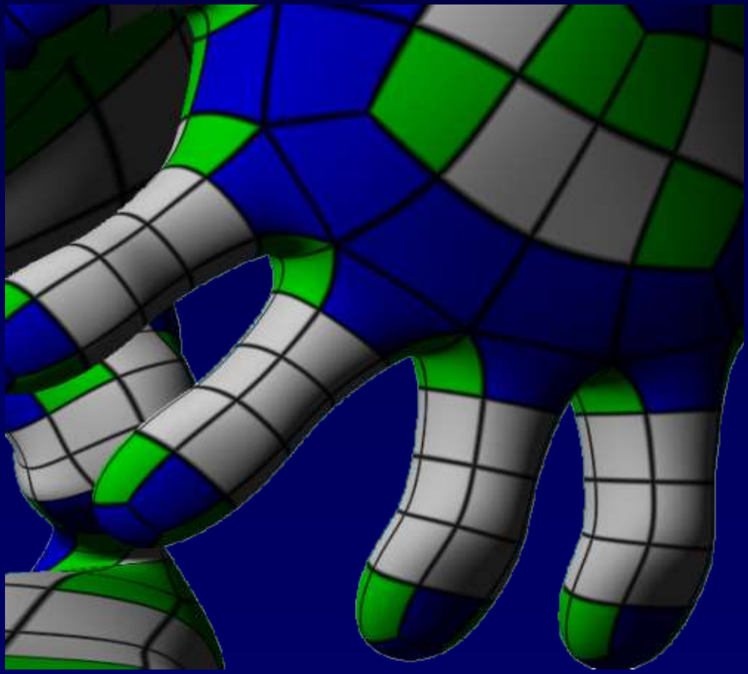
ACC Geo/Tan Patches

Examples

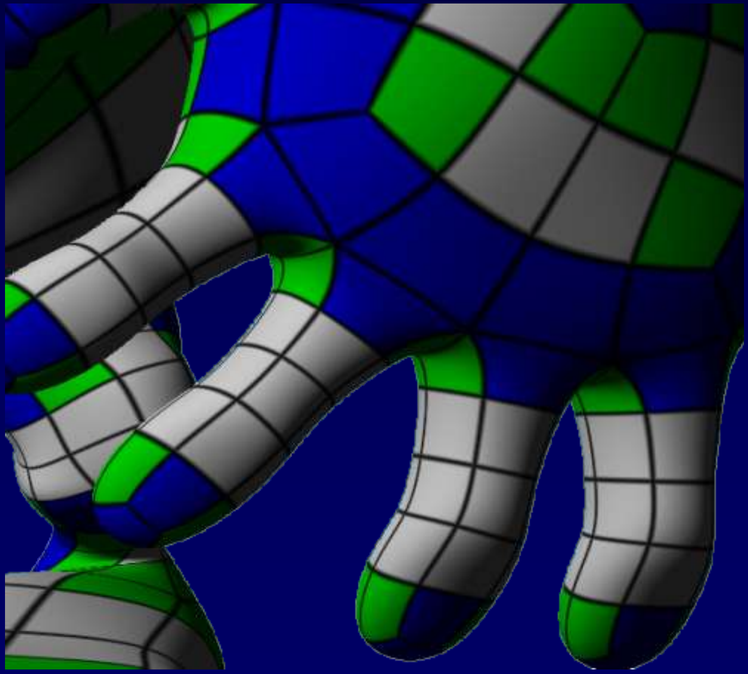


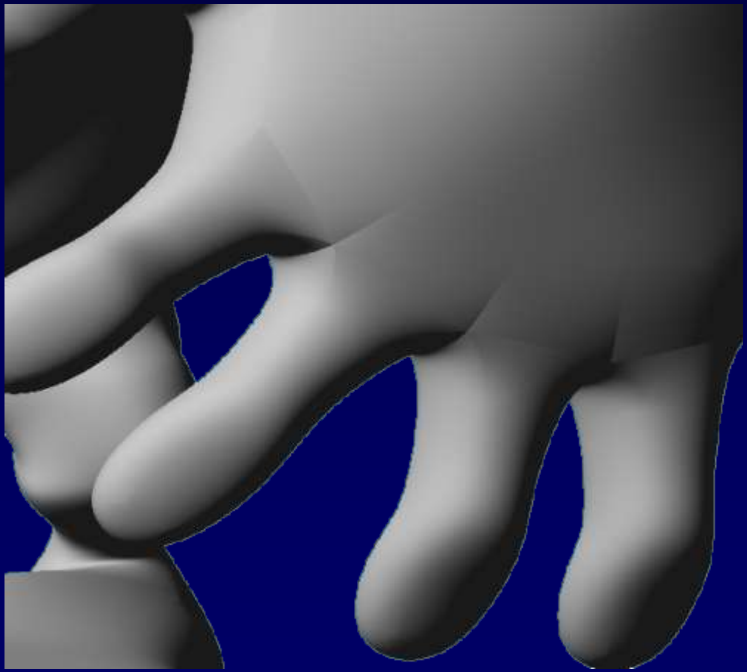
Catmull-Clark Surface

Examples



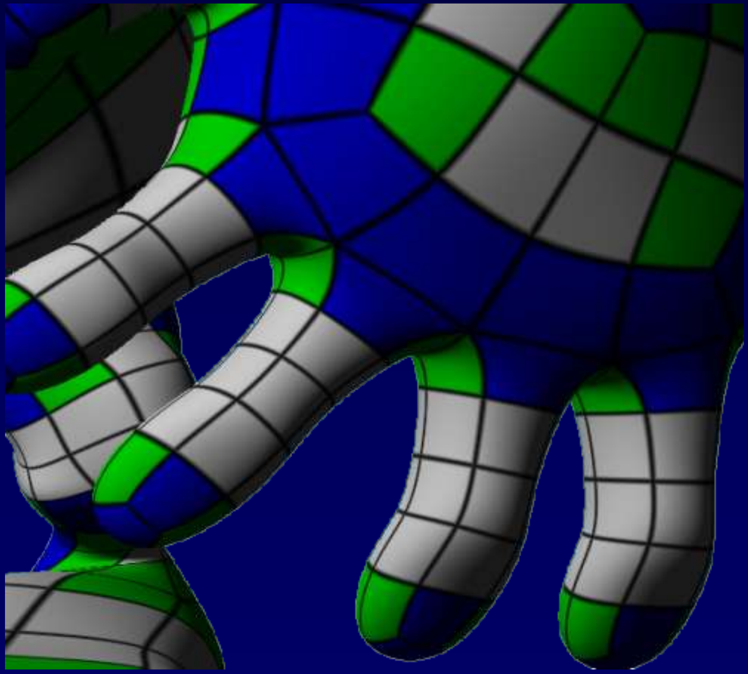
Examples

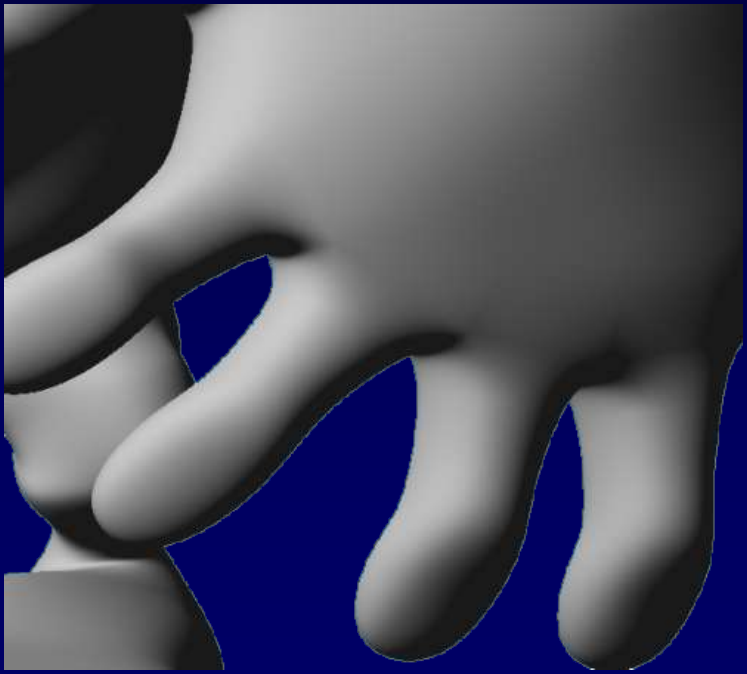




ACC Geometry Patches

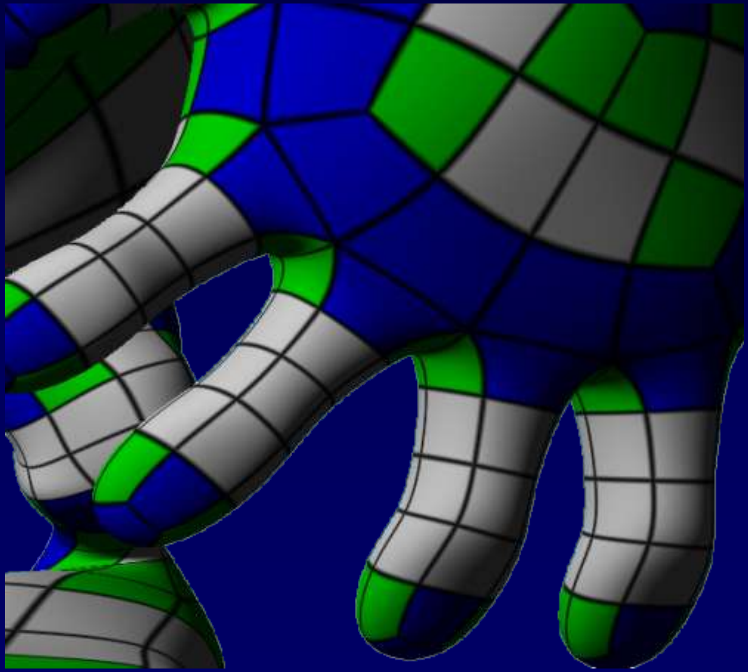
Examples

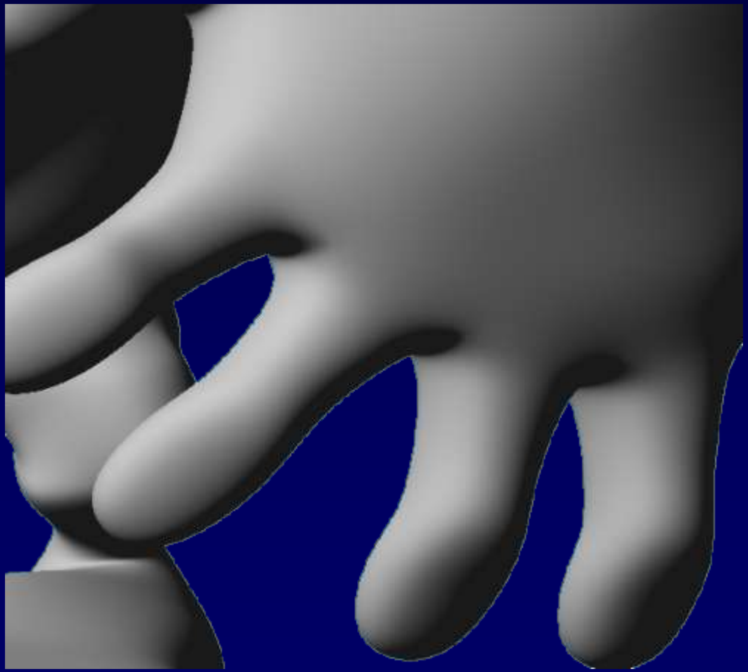




ACC Geo/Tan Patches

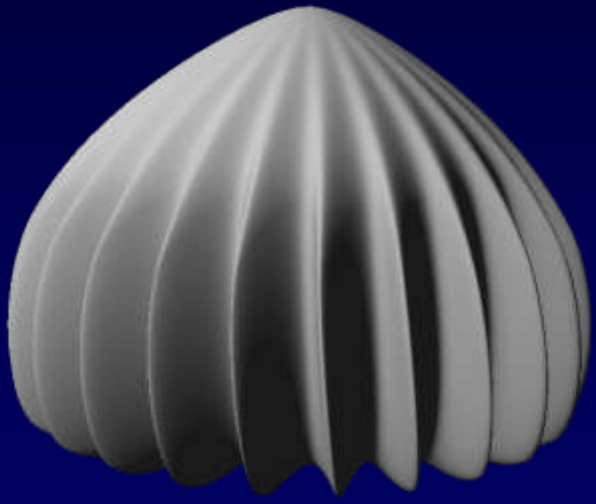
Examples



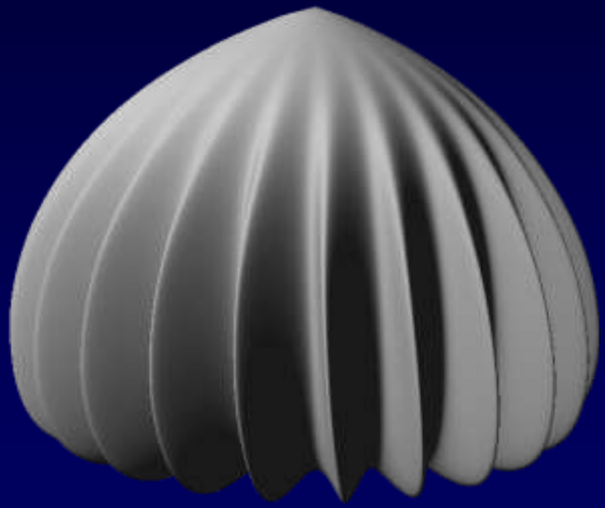


Catmull-Clark Surface

Examples

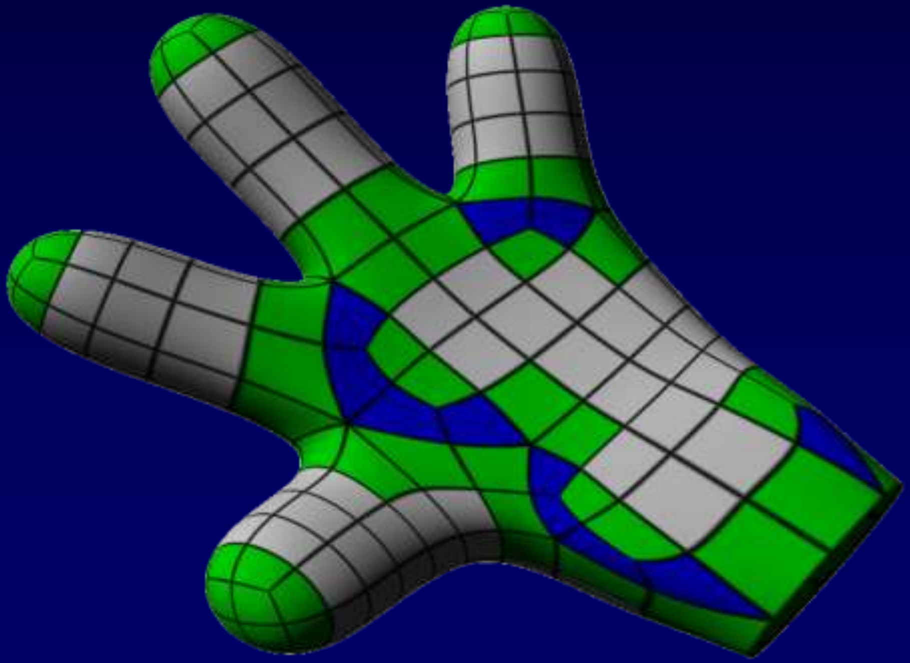


ACC Geo/Tan

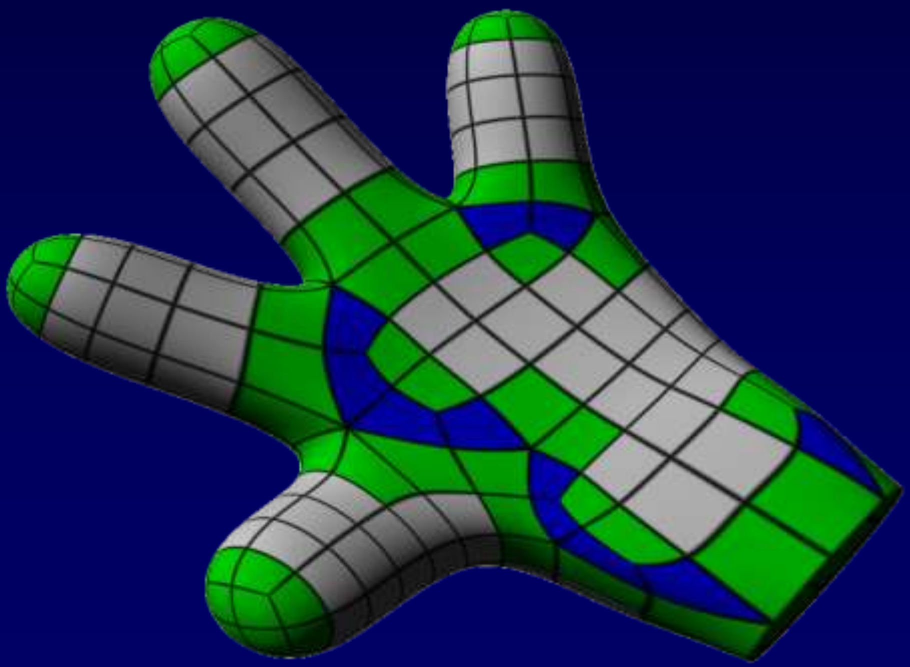


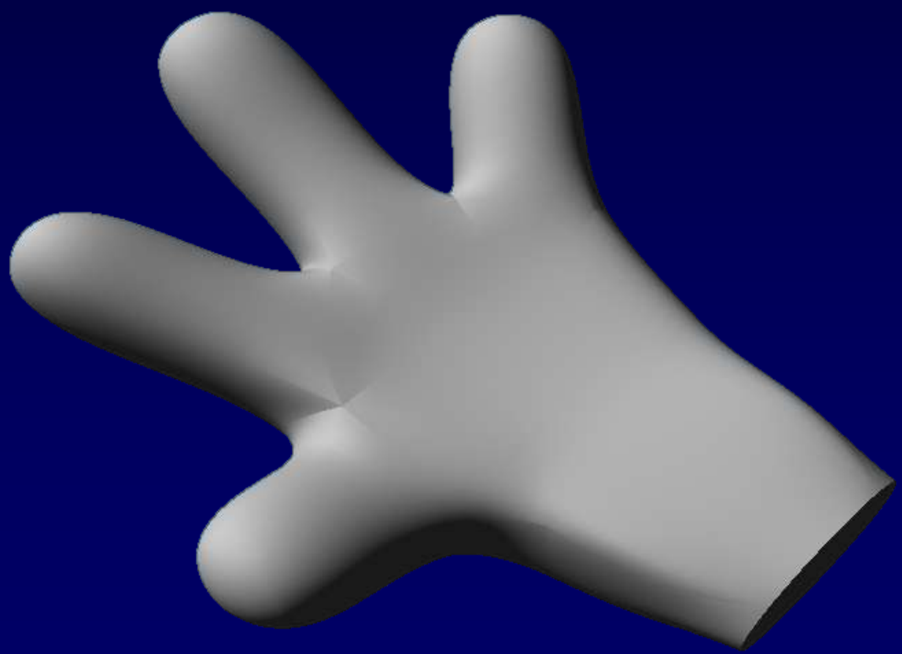
Catmull-Clark

Examples



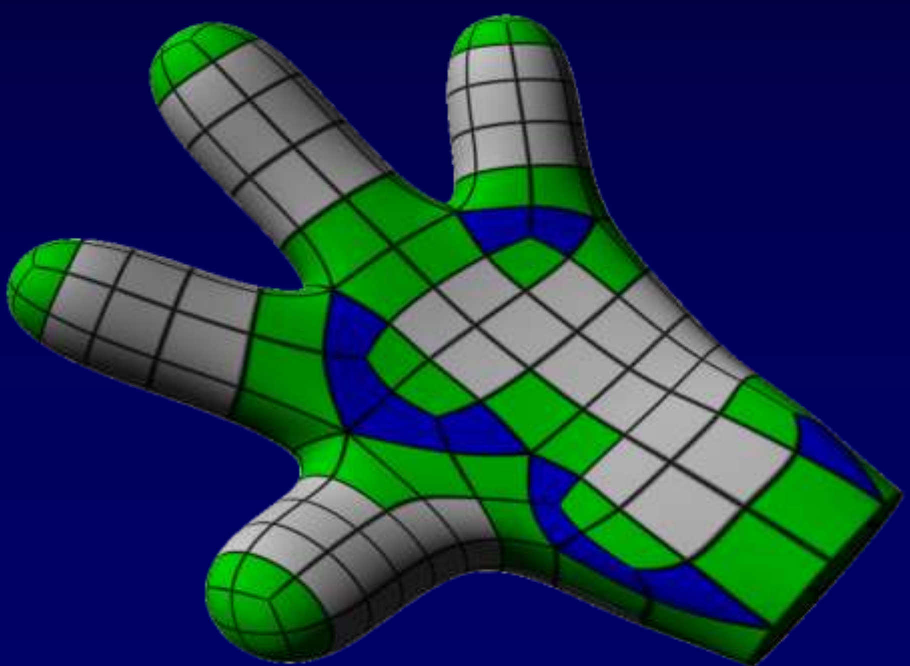
Examples

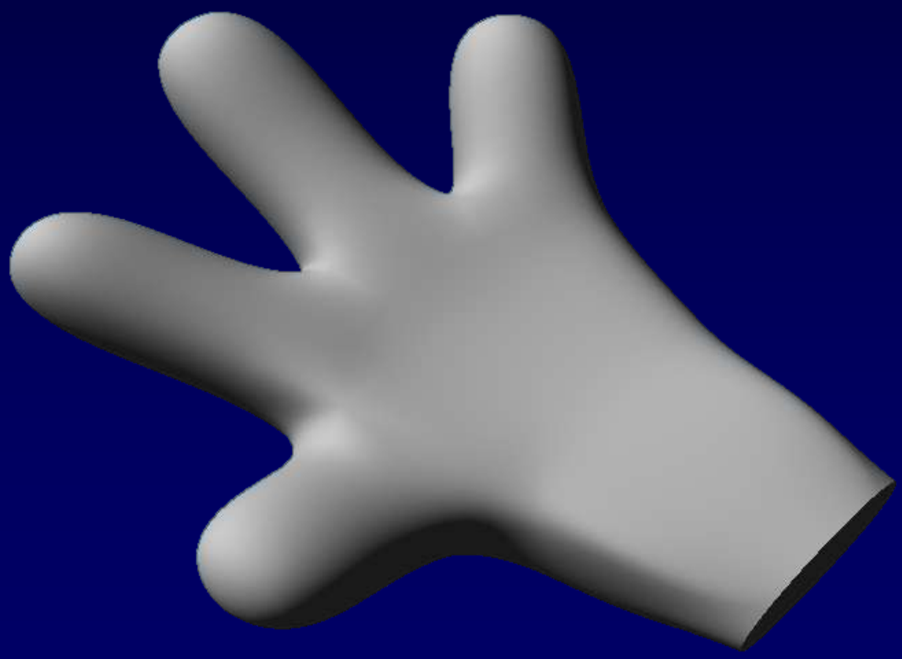




ACC Geometry Patches

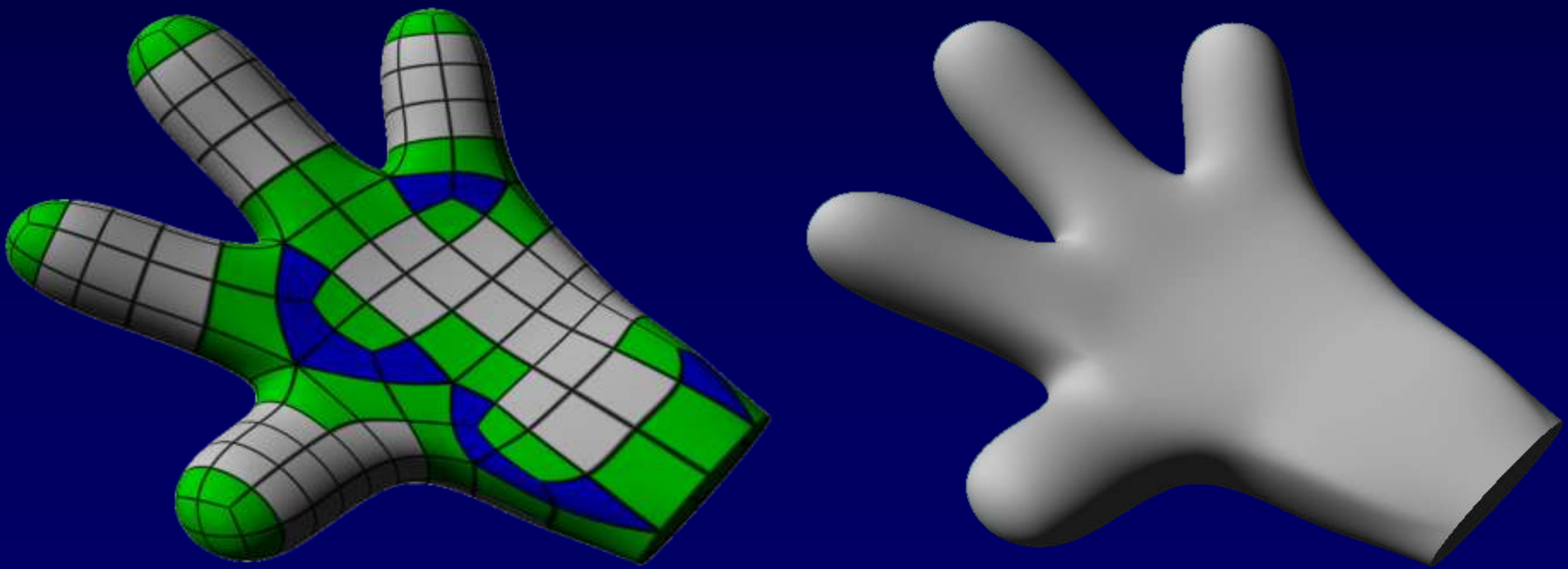
Examples





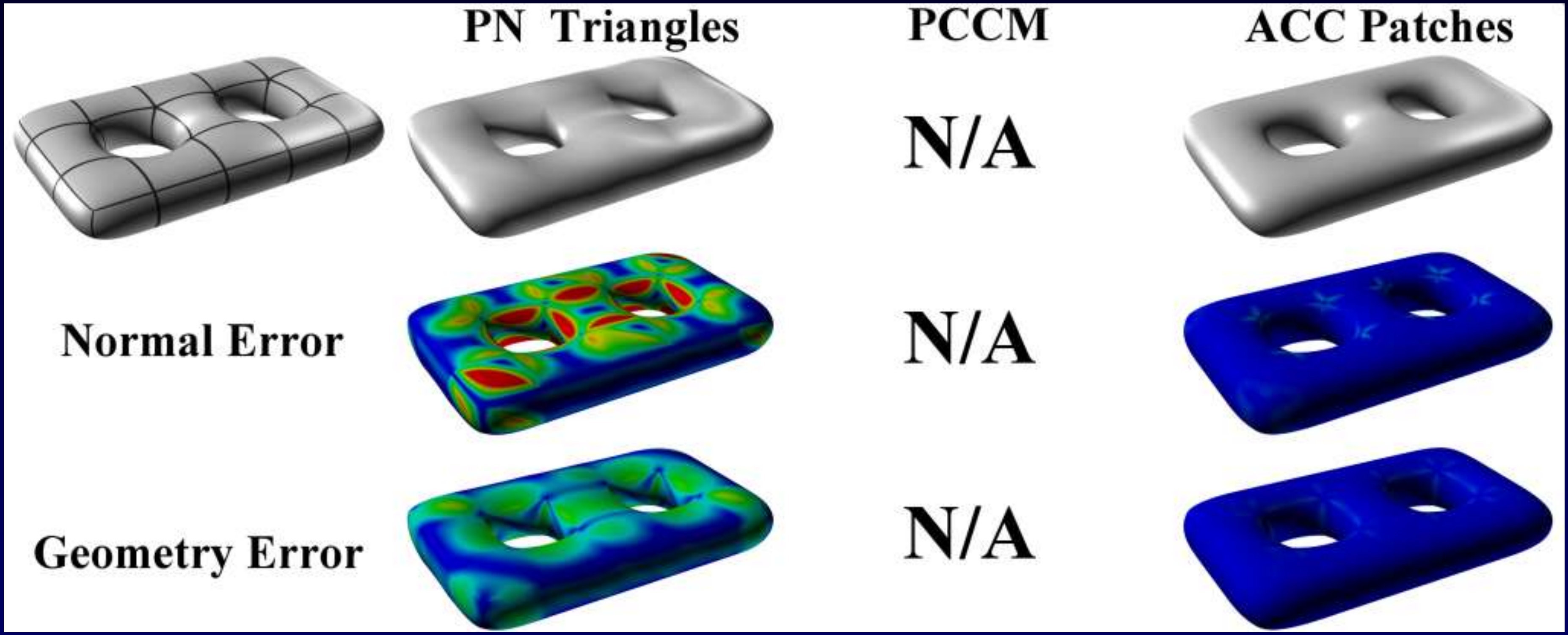
ACC Geo/Tan Patches

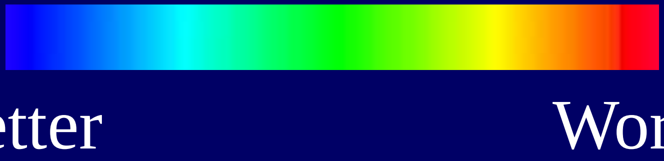
Examples



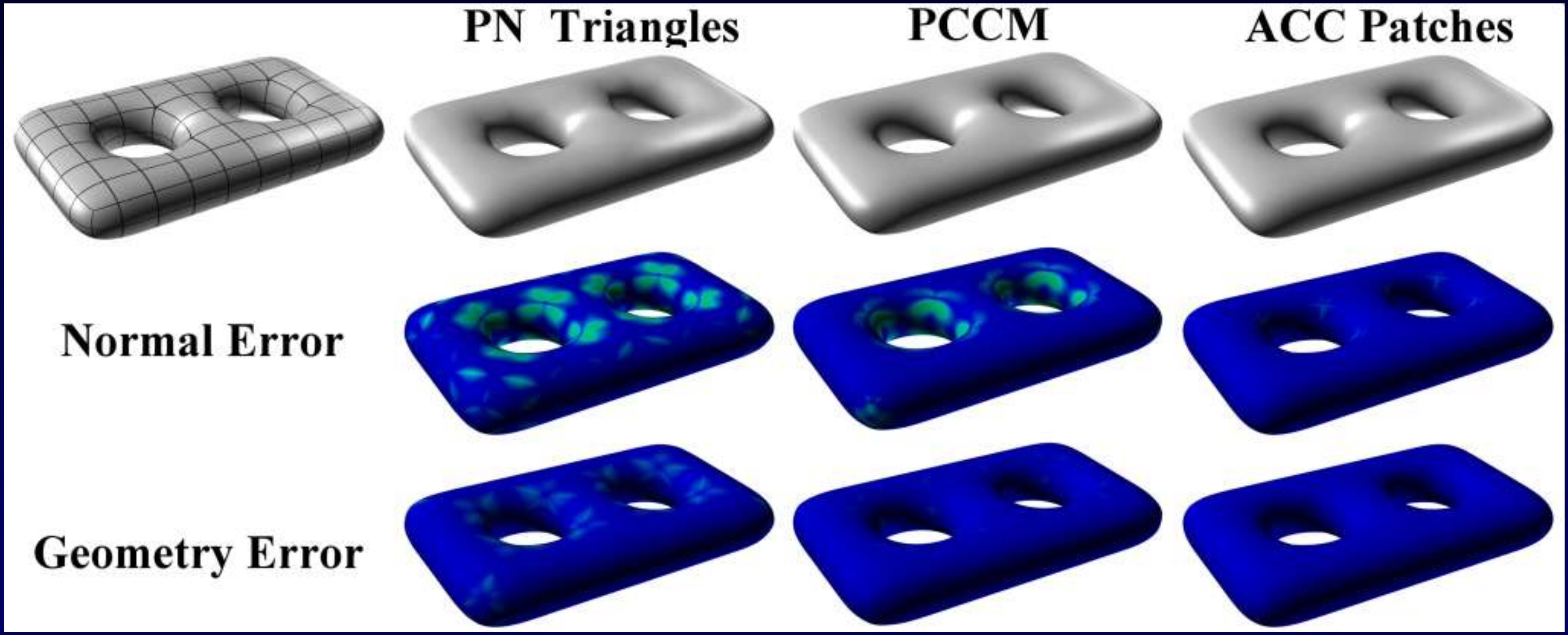
Catmull-Clark Surface

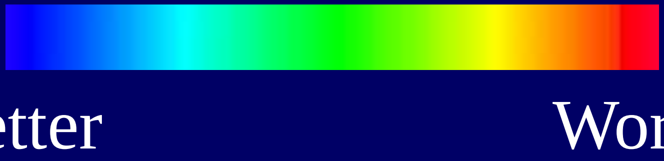
Comparison


PN Triangles
PCCM
ACC Patches
N/A
Normal Error
N/A
Geometry Error
N/A

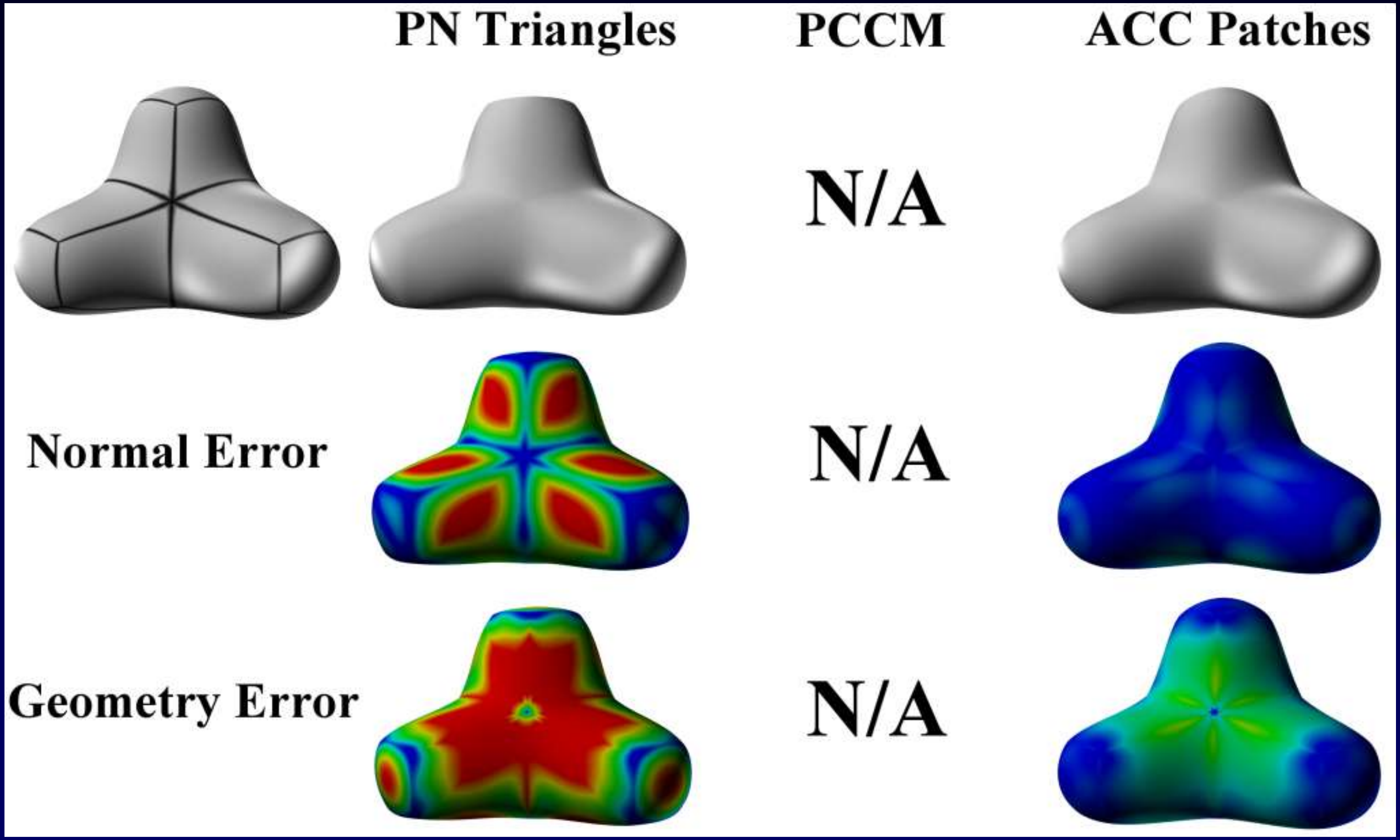

Better
Worse

Comparison

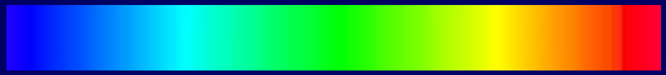

PN Triangles
PCCM
ACC Patches
Normal Error
Geometry Error


Better
Worse

Comparison

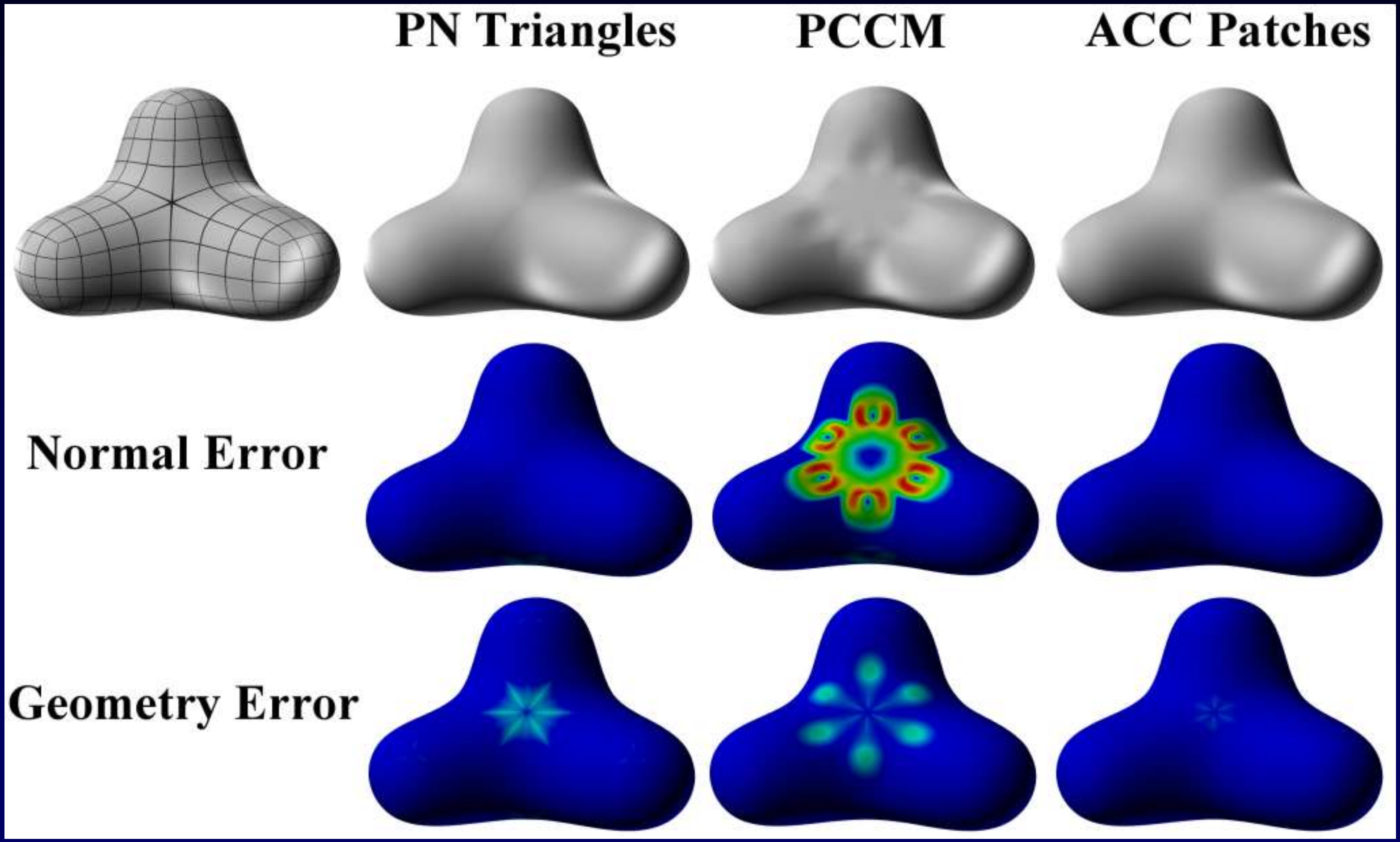


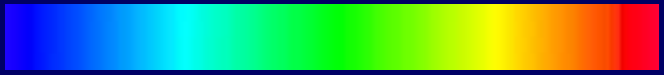
PN Triangles
PCCM
ACC Patches
N/A
Normal Error
N/A
Geometry Error
N/A



Better
Worse

Comparison


PN Triangles
PCCM
ACC Patches
Normal Error
Geometry Error


Better
Worse

Conclusions

- Creates visually smooth surfaces
- Suitable for displacement/normal mapping
- Handles any number of extraordinary vertices
- Simple to evaluate

- Demo part of DirectX March 2008 SDK