DirectX10 Effects

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SIGGRAPH2006

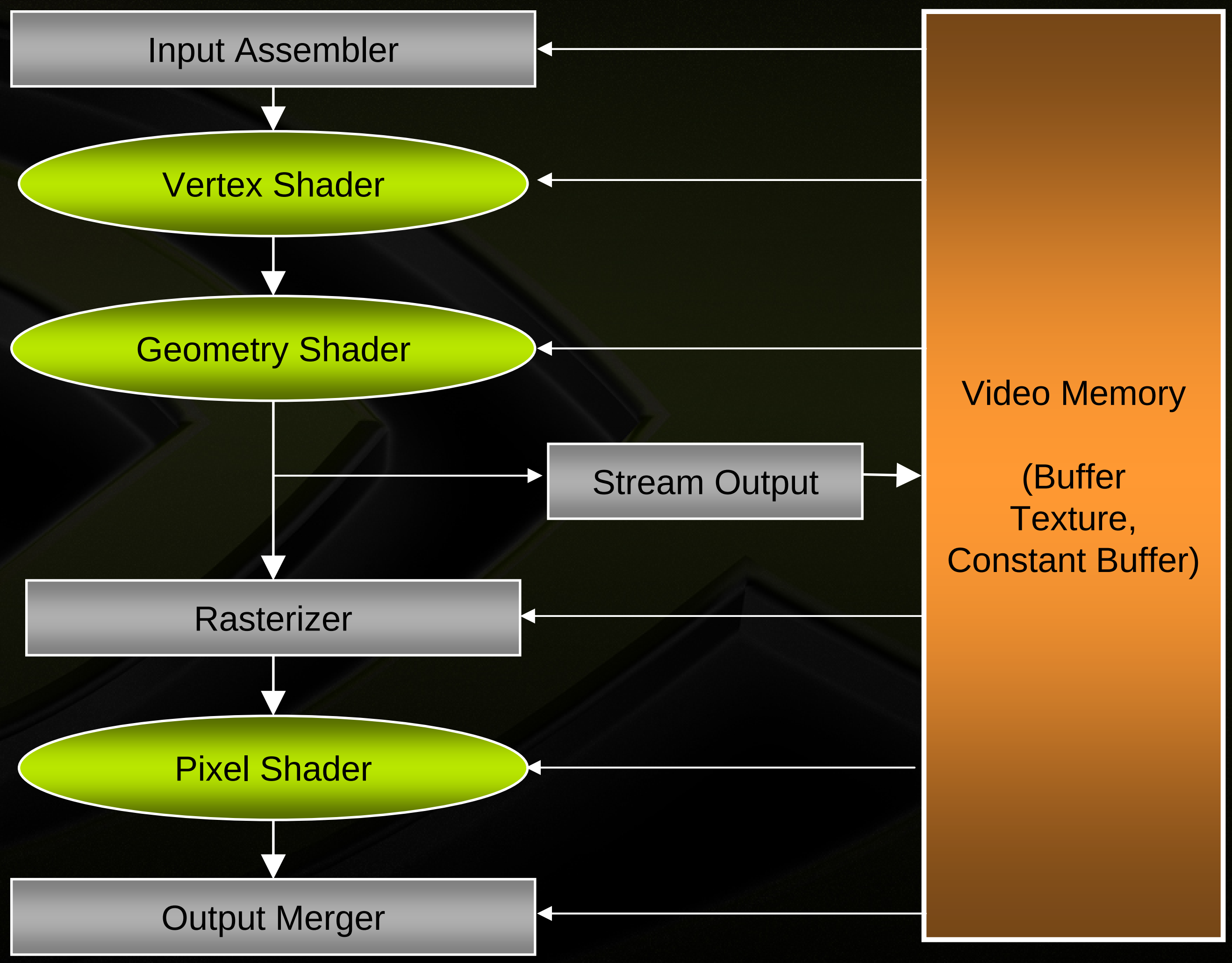
Motivation

- Direct3D 10 is Microsoft's next graphics API
  - Driving the feature set of next generation GPUs
- New driver model
  - Improved performance
- Many new features
  - New programmability, generality
- Cleaned up API
  - Improved state handling. Almost no caps bits!

Agenda

- Short review of DX10 pipeline and features
- Effect Case Studies
  - Fins for fur
  - Cloth
  - Metaballs
- Conclusions

Direct3D 10 Pipeline



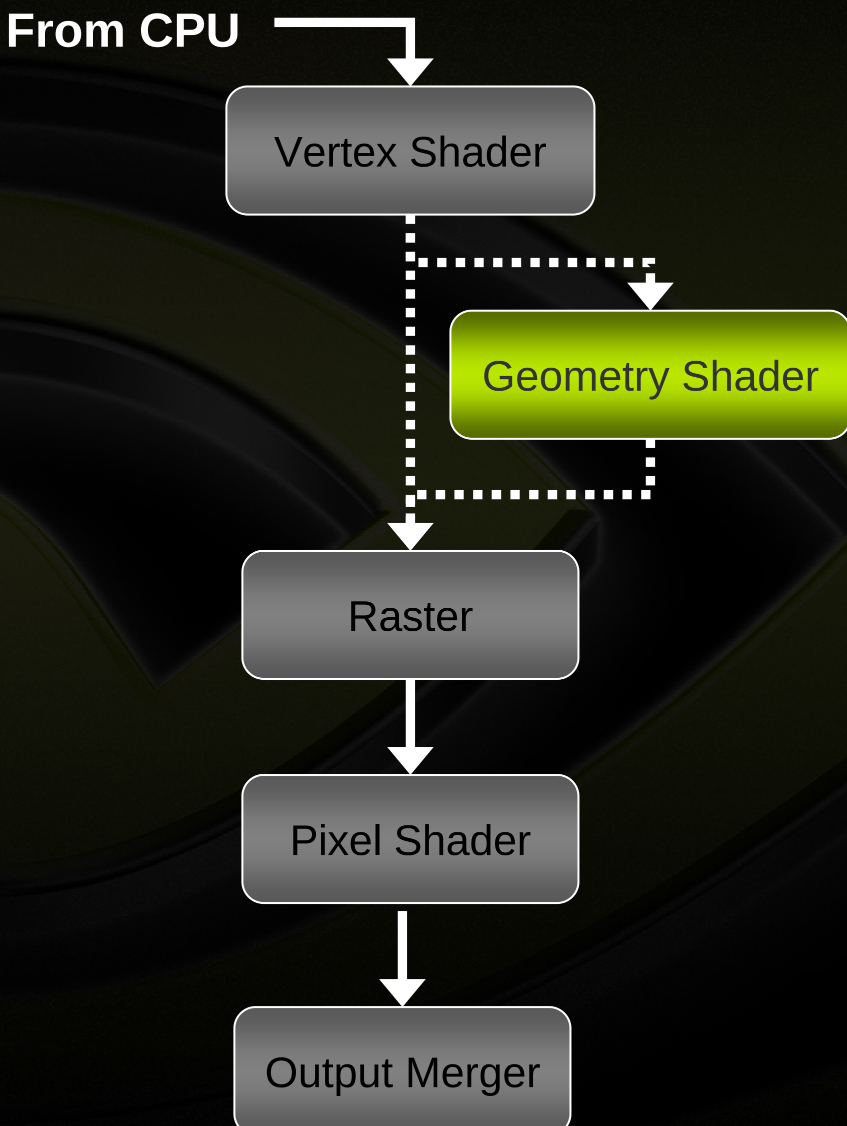
Direct3D 10 New Features

- Geometry shader
- Stream out
- SM 4.0
  - Common shader Instruction Set
  - Integer operations in shaders
  - Load from VB/IB
  - Unlimited instruction count
- Resource Views
  - read depth/stencil buffer
  - Render to vertex buffer
- 8 MRTs
- Render Target arrays
- Texture arrays
- Input assembler generated identifiers; InstanceID, VertexID, PrimitiveID
- Alpha to Coverage

Coming up…

- Overview of Geometry Shader
- Effect: fur
  - Some HLSL code showing the use of the GS
- Overview of Stream Out
- Effect: Cloth
  - Some HLSL code showing the use of the SO
- Effect: Rendering IsoSurfaces

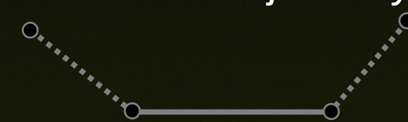
Geometry Shader



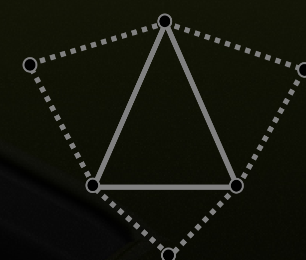
input

Point
Line
Triangle

Line with adjacency



Triangle with adjacency

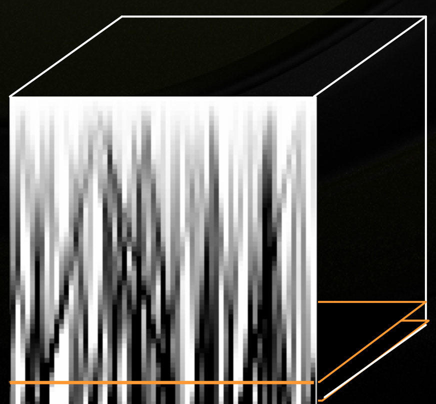


output

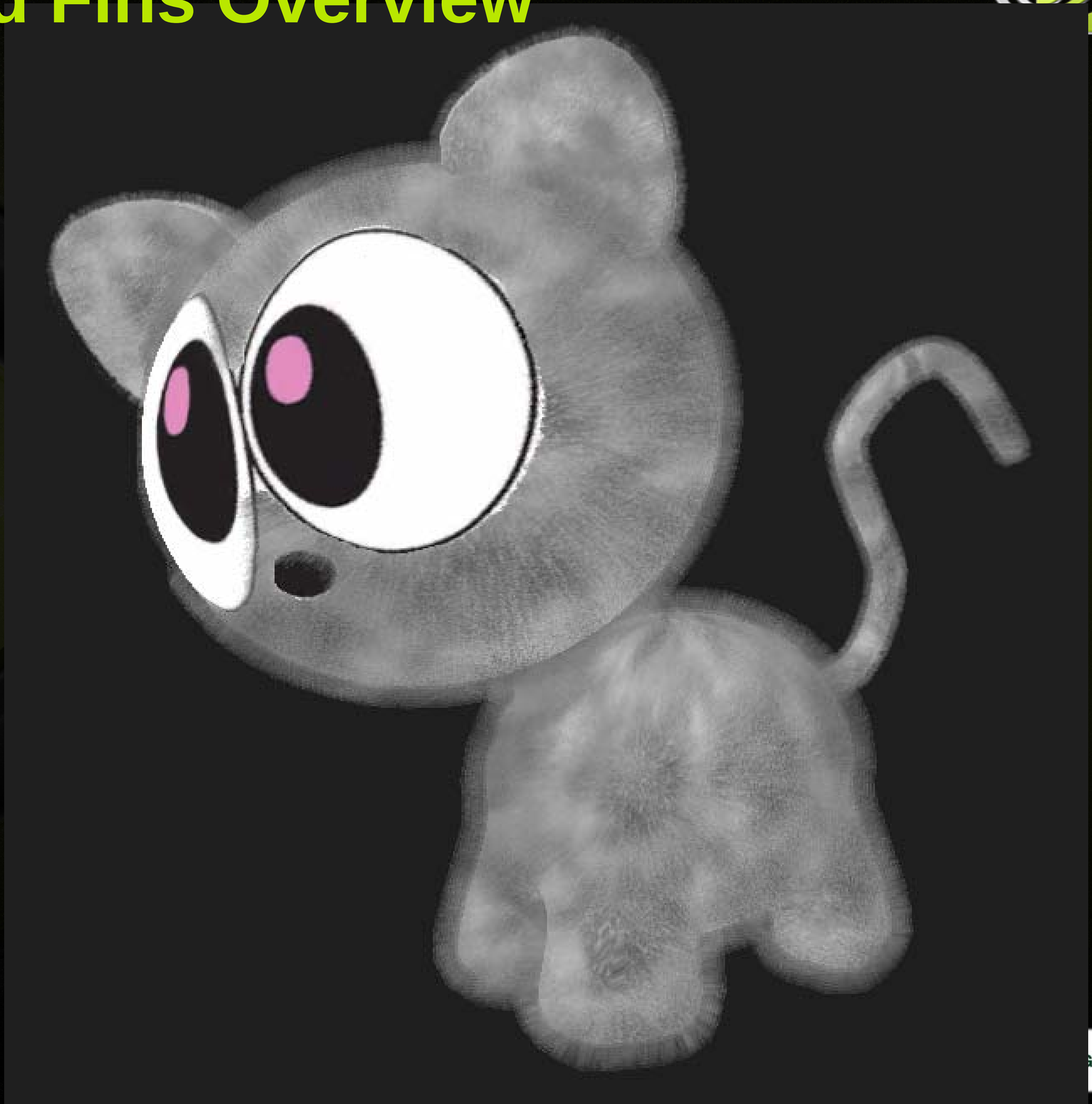
Point list
Line strip
Triangle strip

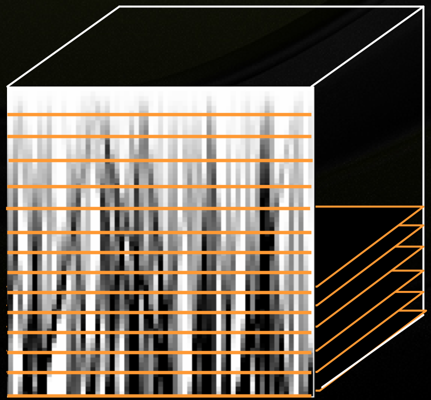
Fur; generating fins on the GPU

Shells and Fins Overview

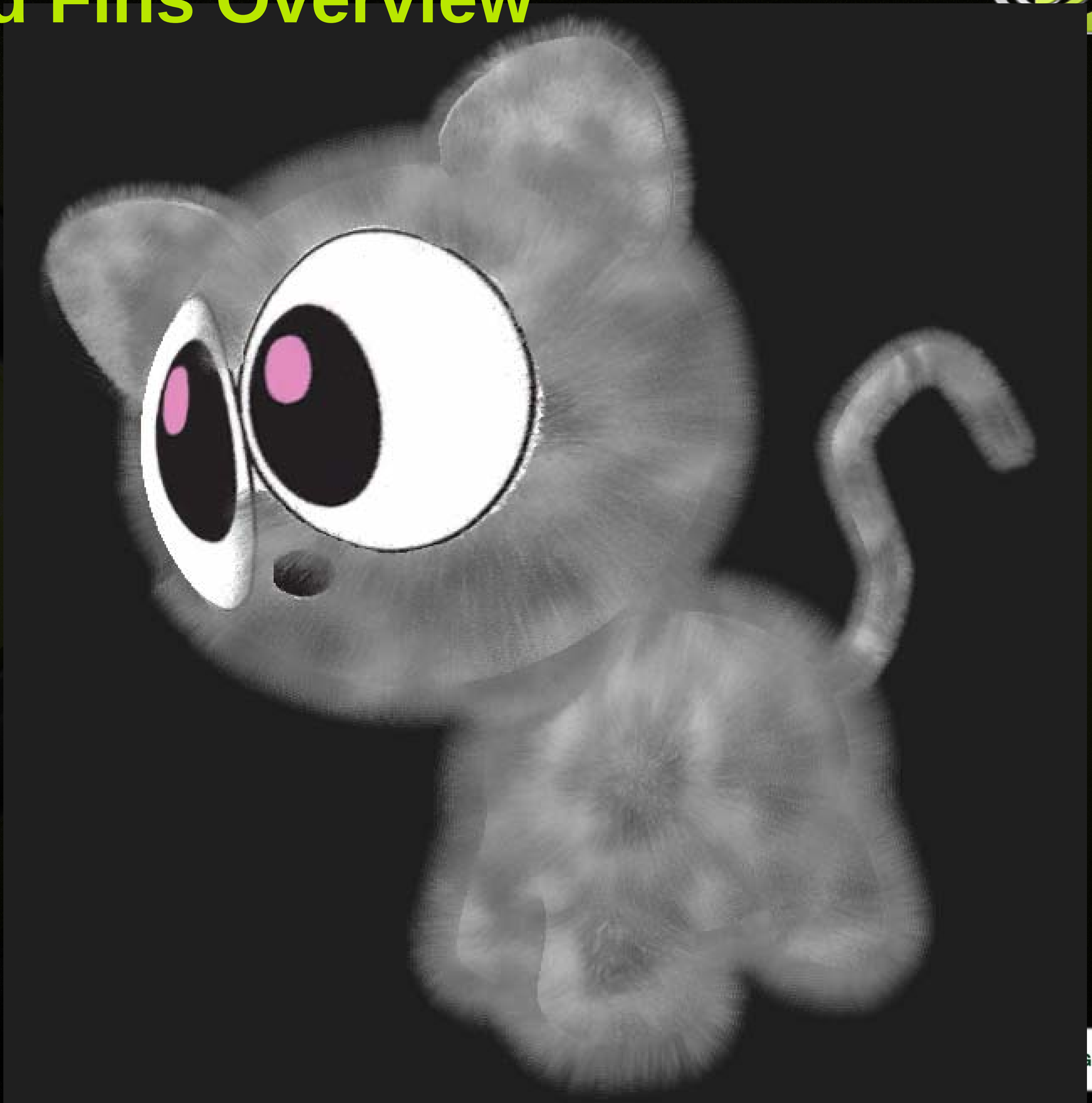


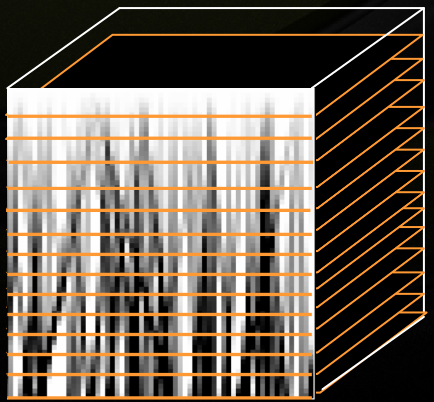
Shells and Fins Overview





Shells and Fins Overview

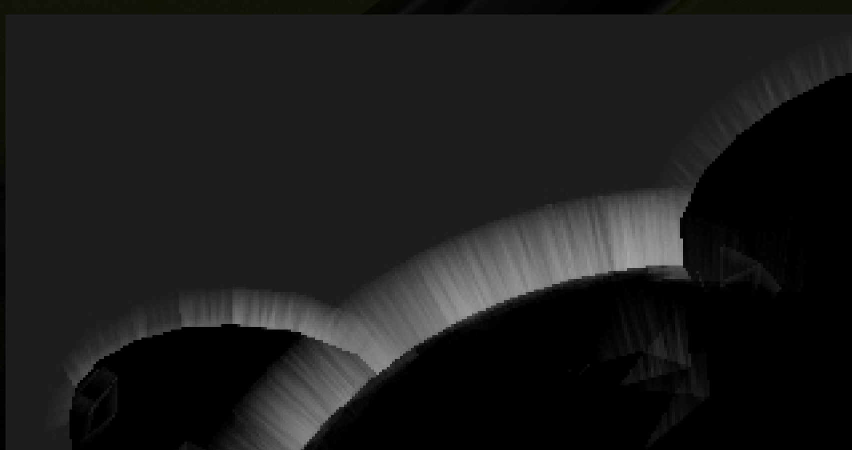




Shells: problems at silhouettes

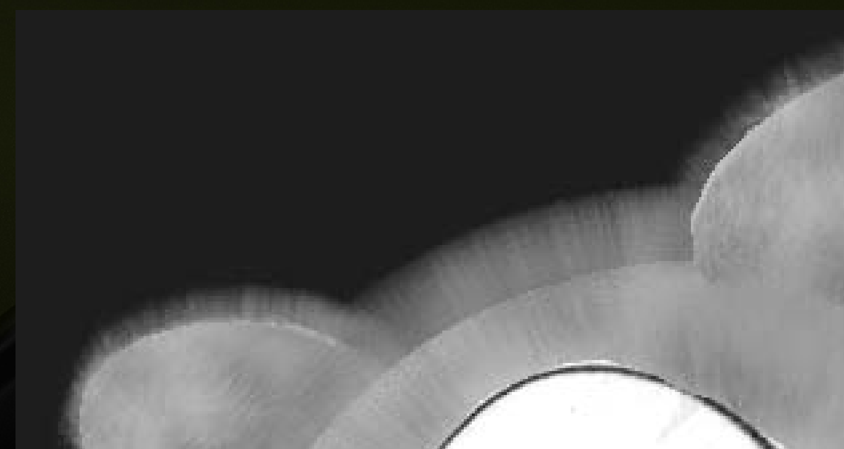
8 shells

+

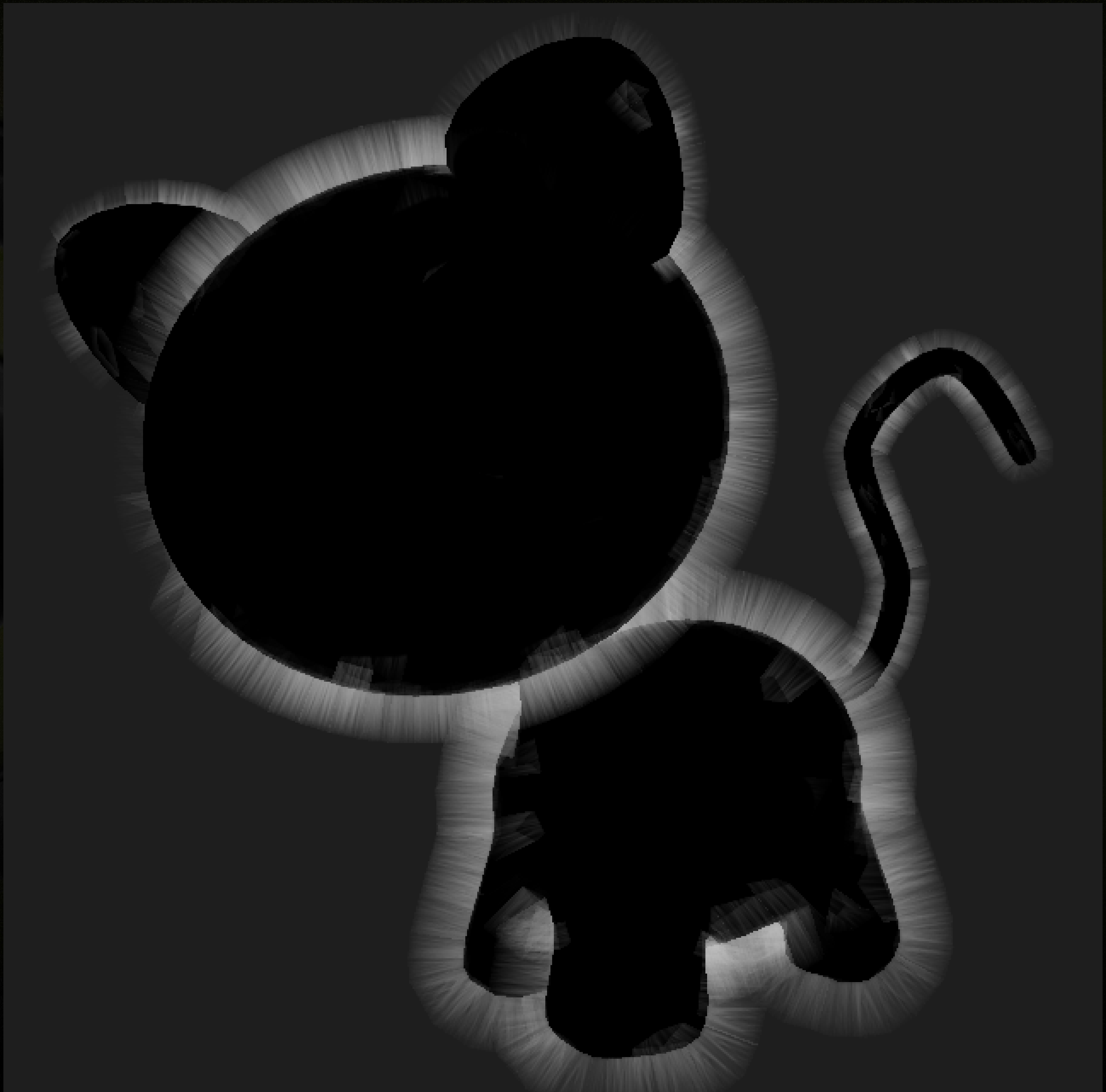


fins

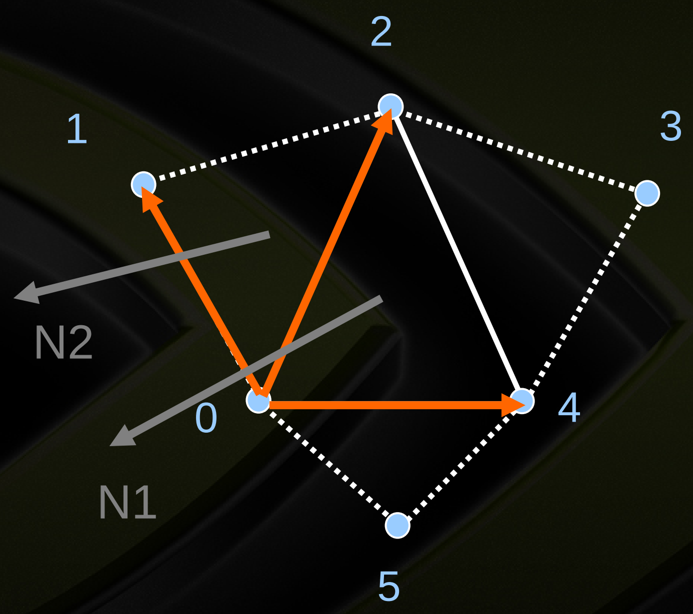
→

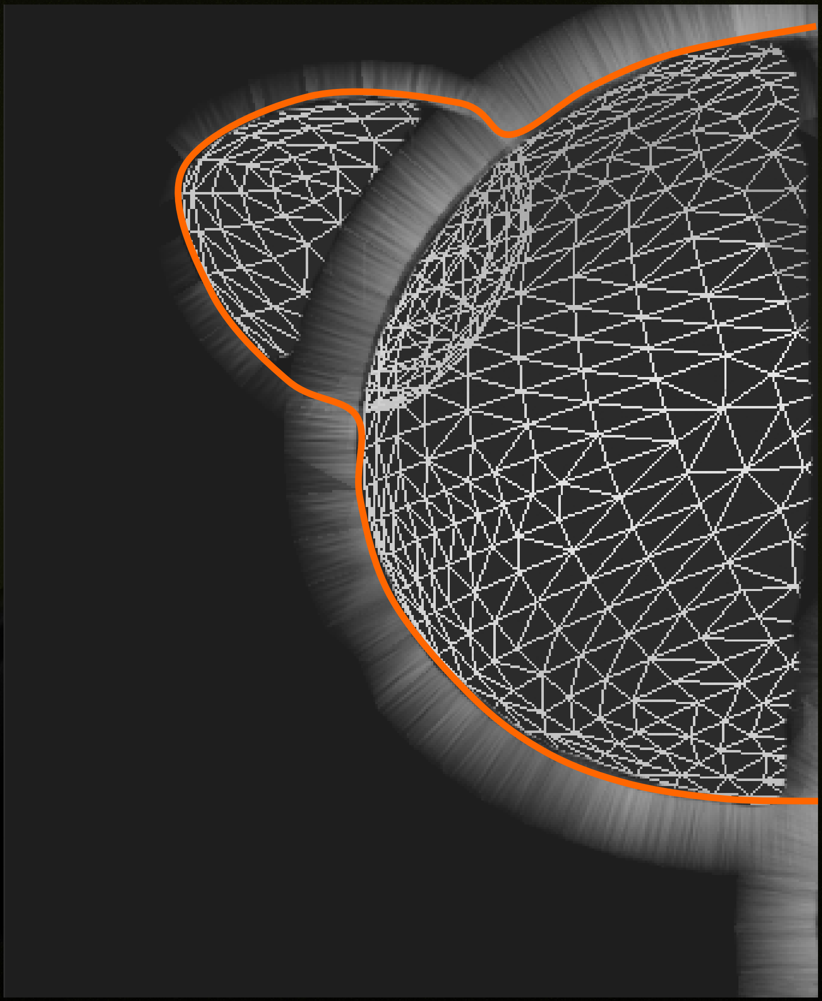


fins

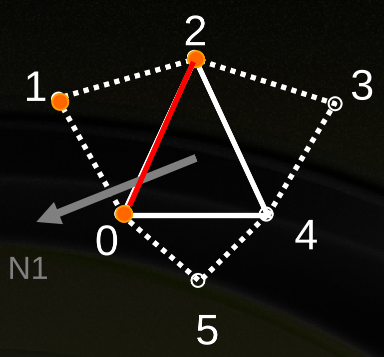


Silhouette detection on the GS





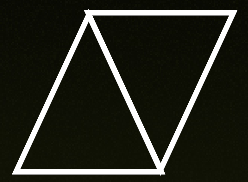
if(dot(eyeVec,N1) > 0 && dot(eyeVec,N2) < 0) input



triangleadj

Geometry Shader

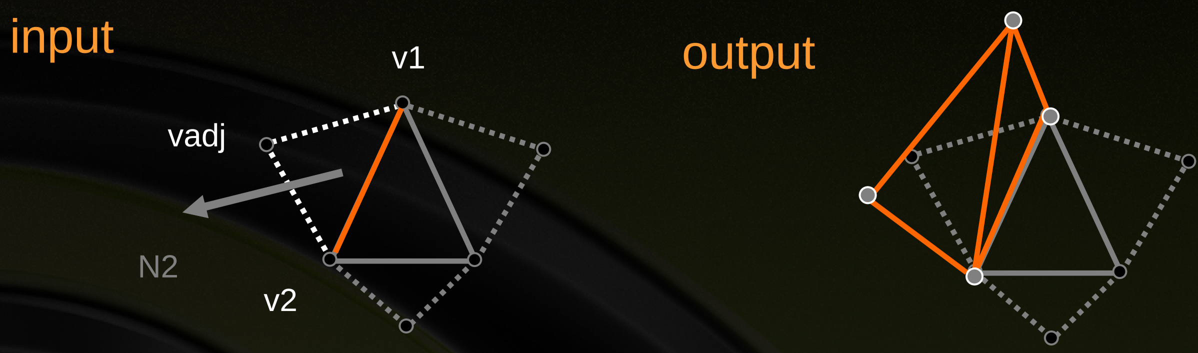
output



TriangleStream

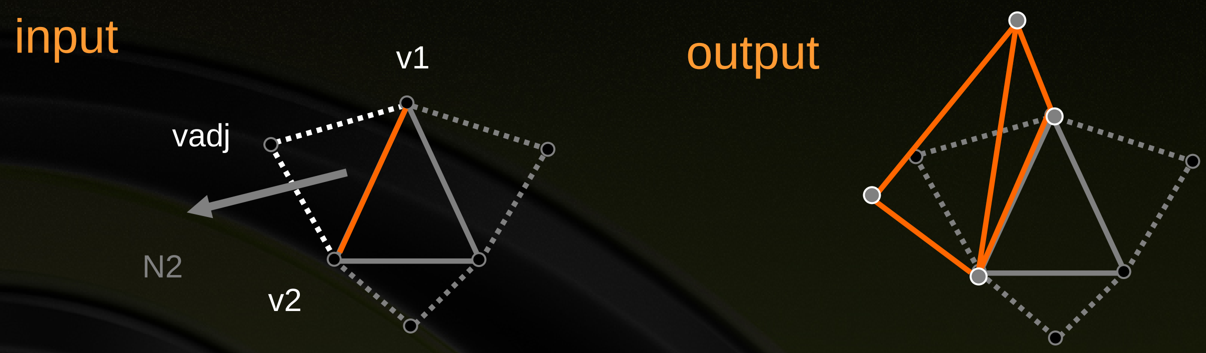
```
//GS shader for the fins
[maxvertexcount(12)]
void GS( triangleadj VS_OUTPUT input[6],
inout TriangleStream<GS_OUTPUT_FINS>TriStream)
{
    //compute the triangle’s normal
    float3 N1 = normalize(cross( input[0].Position - input[2].Position,
                                 input[4].Position -input[2].Position ));
    float3 eyeVec = normalize( Eye – input[0].Position);

    //if the central triangle is front facing, check the other triangles
    if( dot(N1, eyeVec)  > 0.0f )
    {
        makeFin(input[2],input[0],input[1], TriStream);
        makeFin(input[4],input[2],input[3], TriStream);
        makeFin(input[0],input[4],input[5], TriStream);
    }
}
```

Silhouette extrusion




```
void makeFin( VS_OUTPUT v1, VS_OUTPUT v2, VS_OUTPUT vAdj,inout TriangleStream <GS_OUTPUT_FINS>
TriStream )
{  float3 N2 = normalize(cross( v1.Position - v2.Position, vAdj.Position - v2.Position ));
   float3 eyeVec = normalize( Eye - v1.Position );

   //if this is a silhouette edge, extrude it into 2 triangles
   if( dot(eyeVec,N2) < 0 )
   {
       GS_OUTPUT_FINS Out;
       for(int v=0; v<2; v++)
       {
          Out.Position = mul(v1.Position + v*float4(v1.Normal,0)*length, WorldViewProj );
          Out.Normal = mul( v1.Normal, World );
          Out.TextureMesh = v1.Texture;
          Out.TextureFin = float2(0,1-v);
          Out.Opacity = opacity;
          //append new vertices to the stream to create the fin
          TriStream.Append(Out);
       }
```

Silhouette extrusion



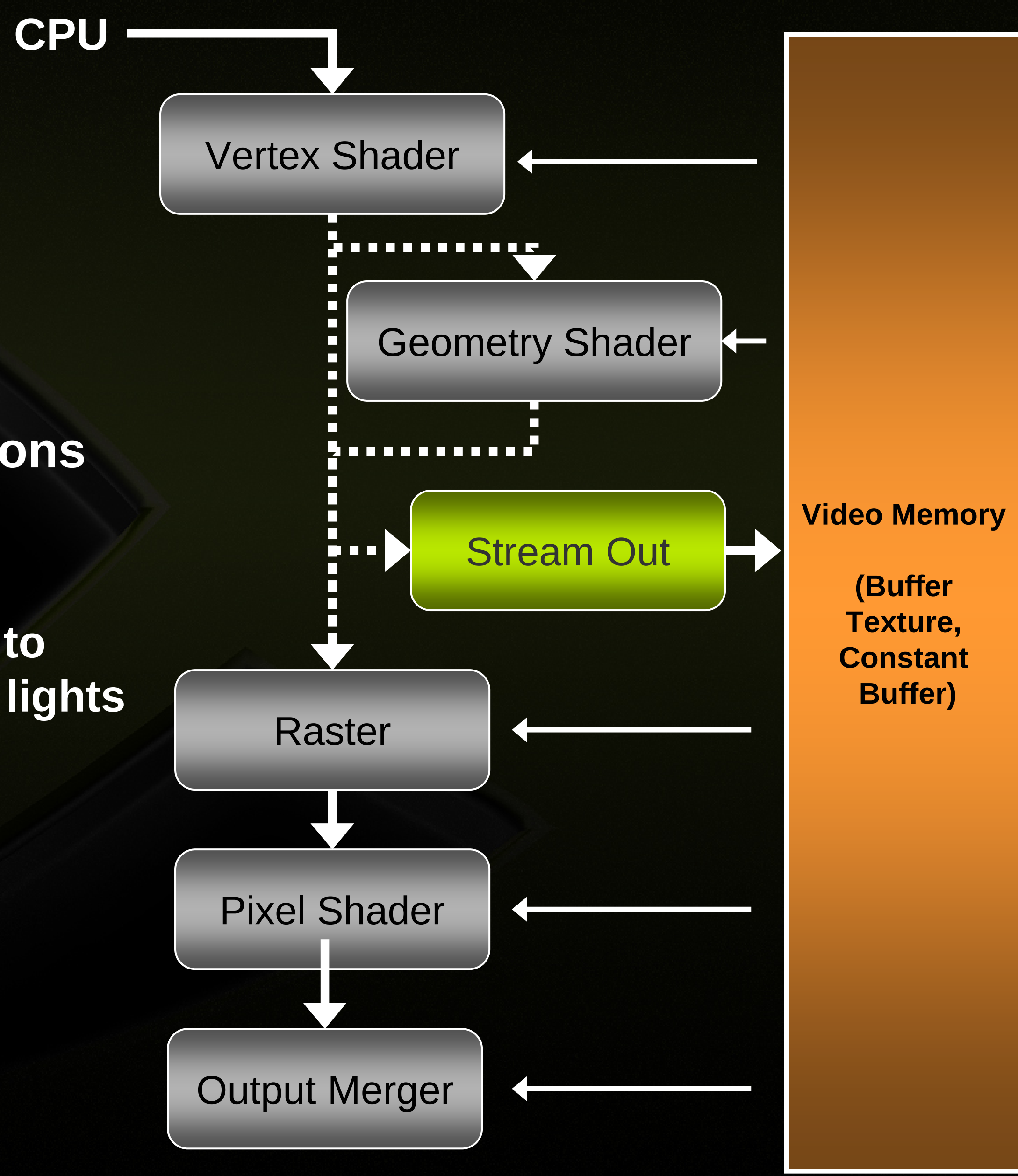

```
for(int v=0; v<2; v++)
{
   Out.Position = mul(v2.Position + v*float4(v2.Normal,0)*length, WorldViewProj );
   Out.Normal = mul( v2.Normal, World );
   Out.TextureMesh = v2.Texture;
   Out.TextureFin = float2(1,1-v);
   Out.Opacity = opacity;

   TriStream.Append(Out);
}

TriStream.RestartStrip();
}}
```

Some more Geometry Shader applications

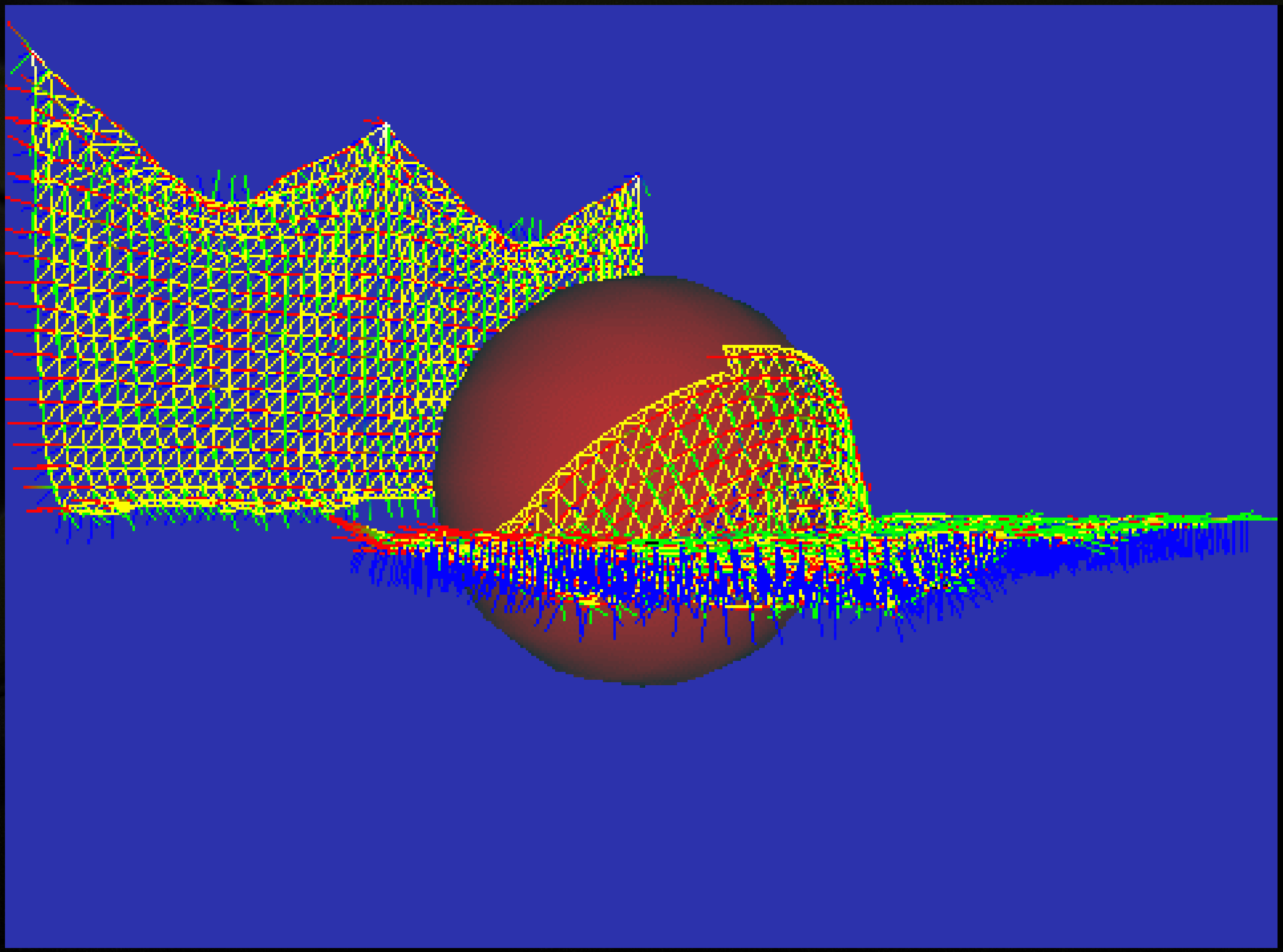
- Silhouette detection and extrusion for:
  - Shadow volume generation
  - NPR
- Access to topology for calculating things like curvature
- Render to cube map in single pass
  - In conjunction with Render Target arrays
- GPGPU
  - enables variable number of outputs from shader

Stream Out

- Allows storing output from geometry shader or vertex shader to buffer
- Enables multi-pass operations on geometry, e.g.
  - Recursive subdivision
  - Store results of skinning to buffer, reuse for multiple lights

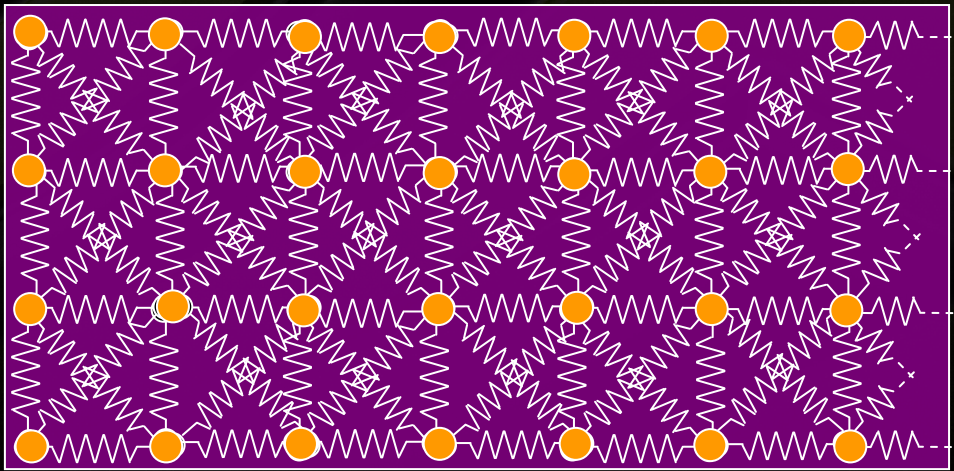


Cloth on the GPU



Cloth as a Set of Particles

- Each particle is subject to:
  - A force (gravity, wind, drag, etc.)
  - Various constraints:
    - To maintain overall shape (springs)
    - To prevent interpenetration with the environment (collision)



Cloth

Particles

Springs

Cloth Simulation

- Apply force to all particles
- For as many times as necessary:
  - Apply spring constraints
  - Apply collision constraints
- Render mesh

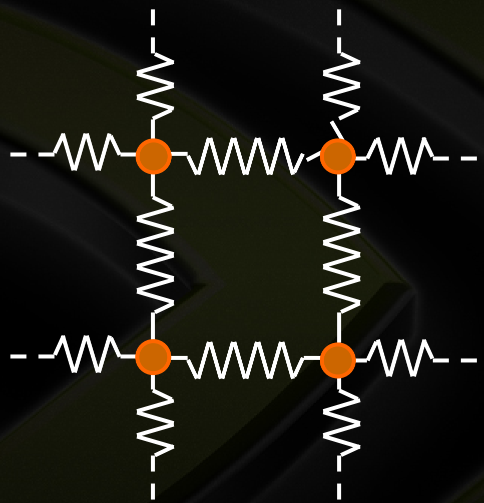
Constraints

- The constraints create a system of equations to be solved at each time step

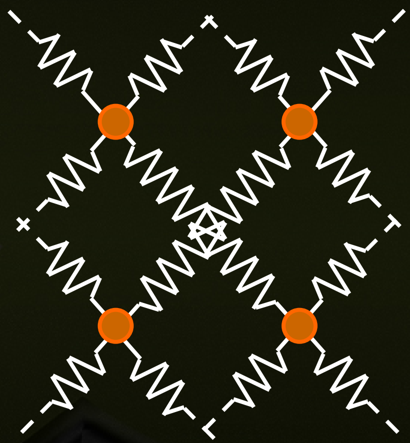
- Use **explicit integration**:
  constraints are resolved by **relaxation**, that is by enforcing them one after the other for a given number of iterations

Spring Constraints

- **Particles are linked by springs:**



Structural springs

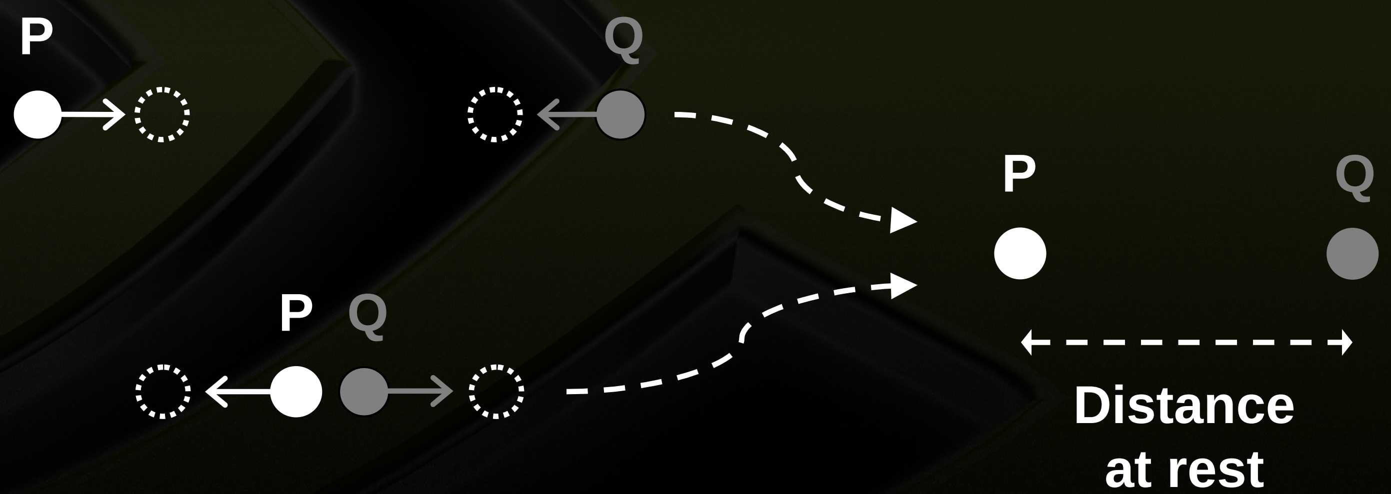


Shear springs

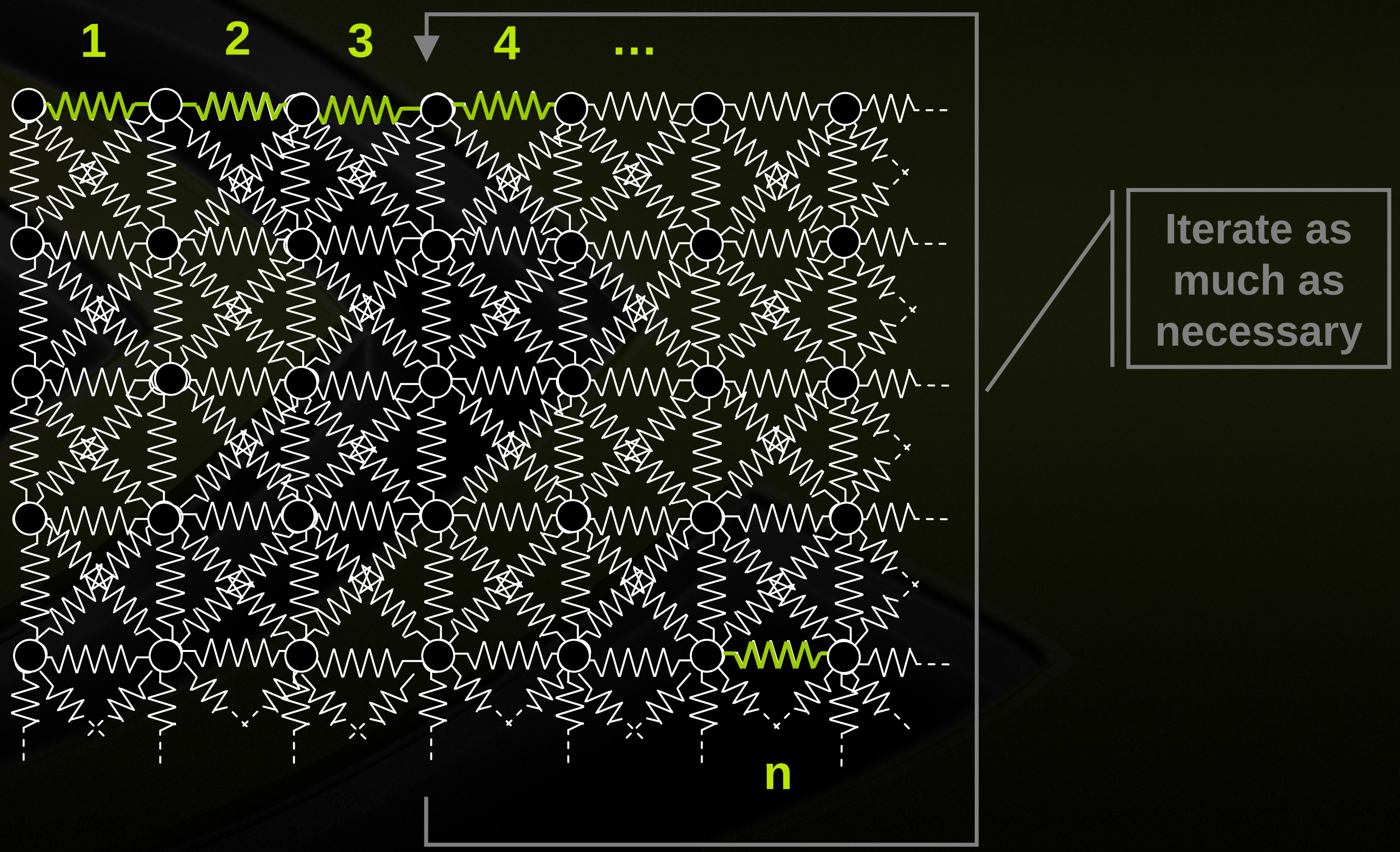
- **A spring is simulated as a distance constraint between two particles**

Distance Constraint

- A distance constraint DC(P, Q) between two particles P and Q is enforced by moving them away or towards each other:



Sequential update

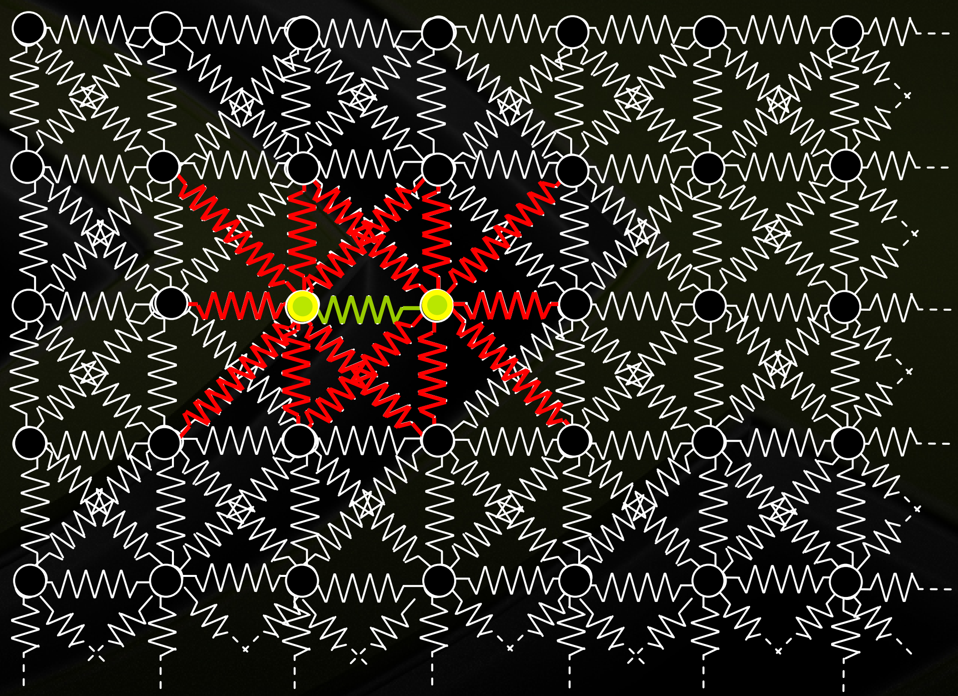


How do we update the springs? We could update them one at a time …

Sequential update

But that's too slow.

On the GPU we want to do as many updates in parallel as possible



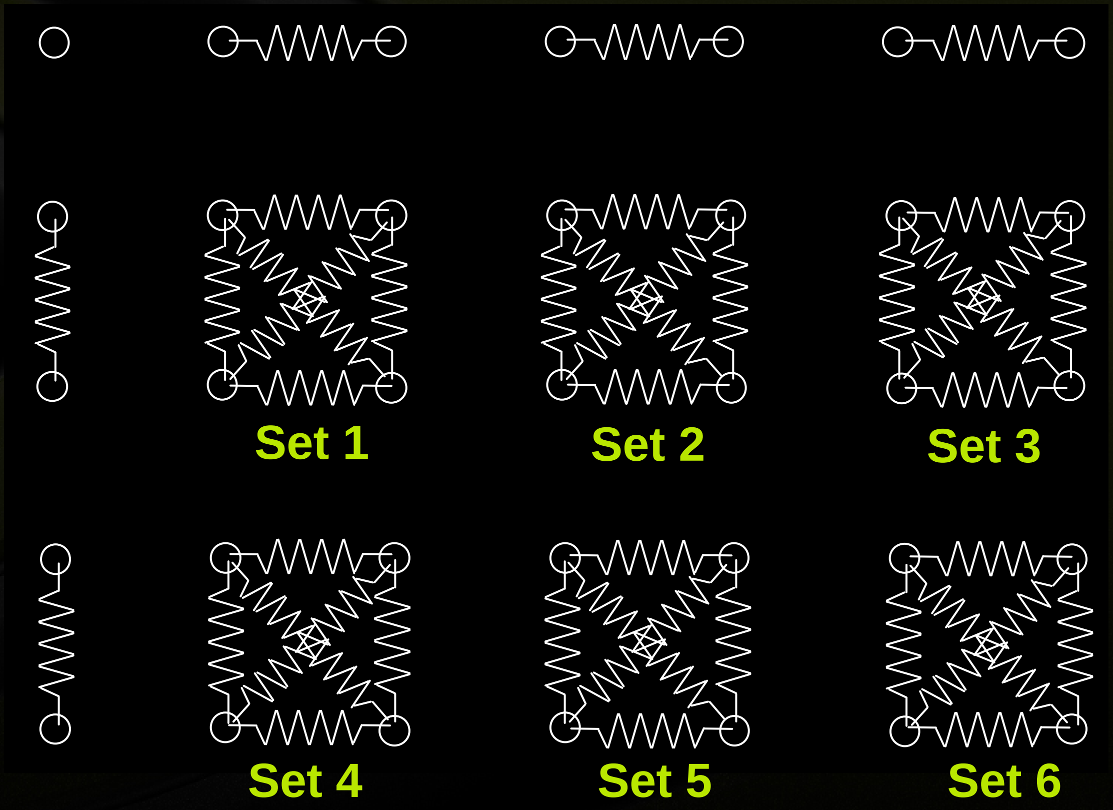
However, we cannot update all springs in parallel; for example, the green spring cannot be updated at the same time as the red springs, since they affect the same particles

Parallel update

- The solution is to partition the springs into batches of independent sets, such that any given particle is only affected by one set in a batch

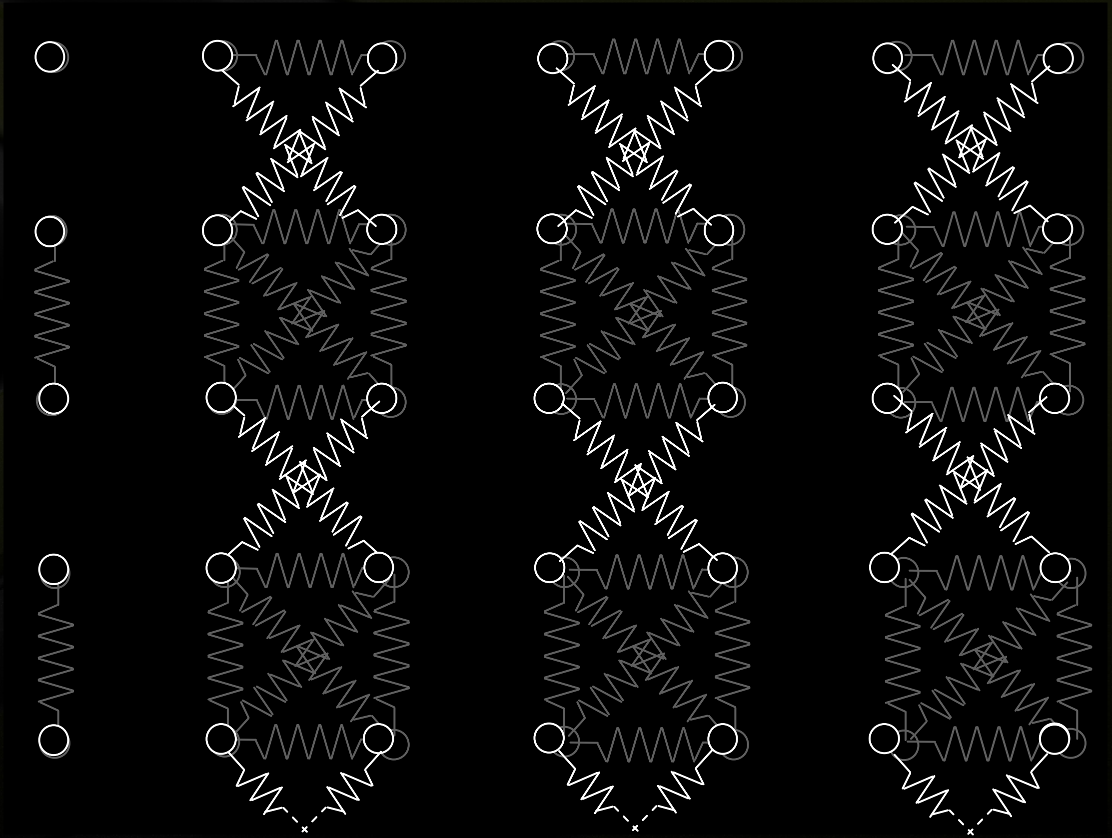
Parallel update

Batch 1



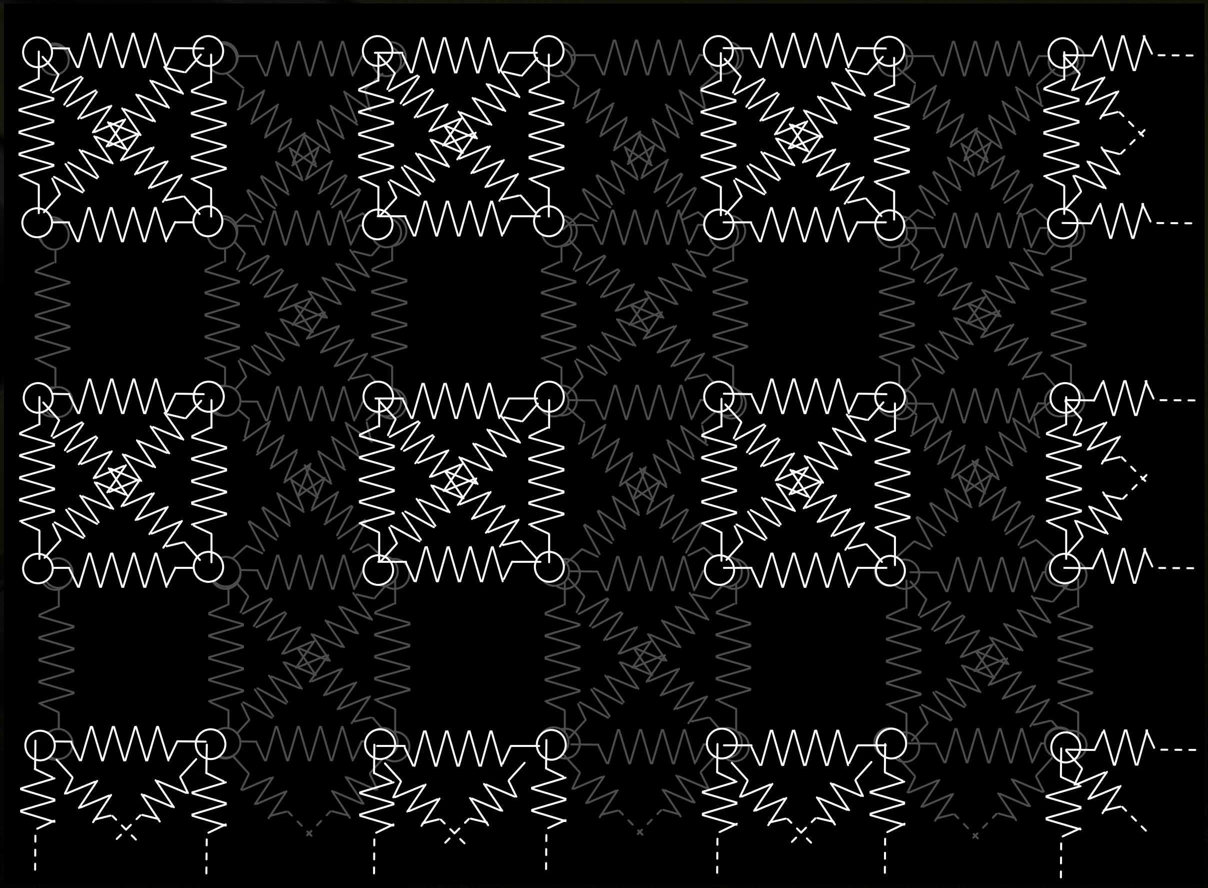
Parallel update

Batch 2



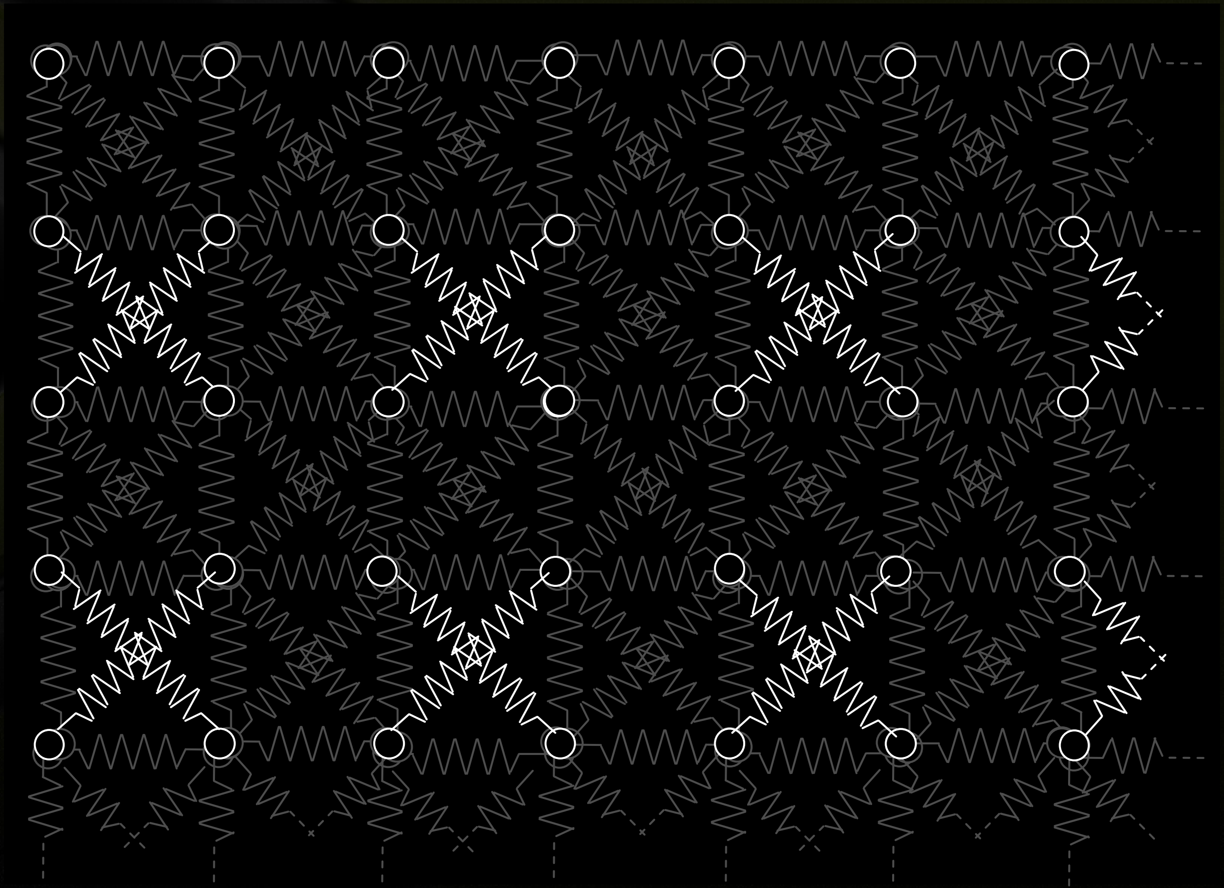
Parallel update

Batch 3



Parallel update

Batch 4



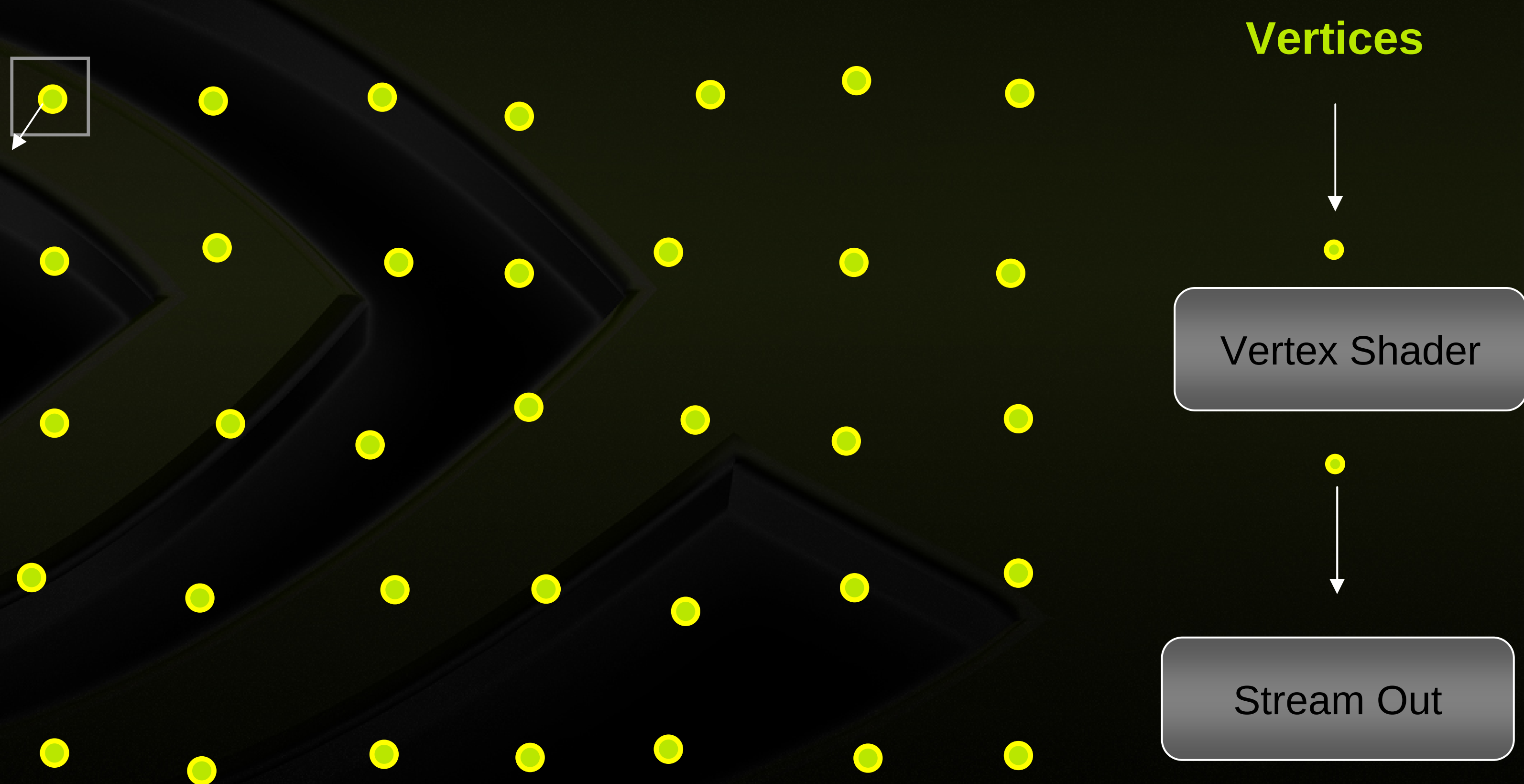
Cloth Simulation

- Apply force to all particles
  synchronize
- For as many times as necessary:
  - For all 4 batches
    - Apply spring constraints
      Synchronize
  - Apply collision constraints
    Synchronize
- Render mesh

DirectX10 Implementation

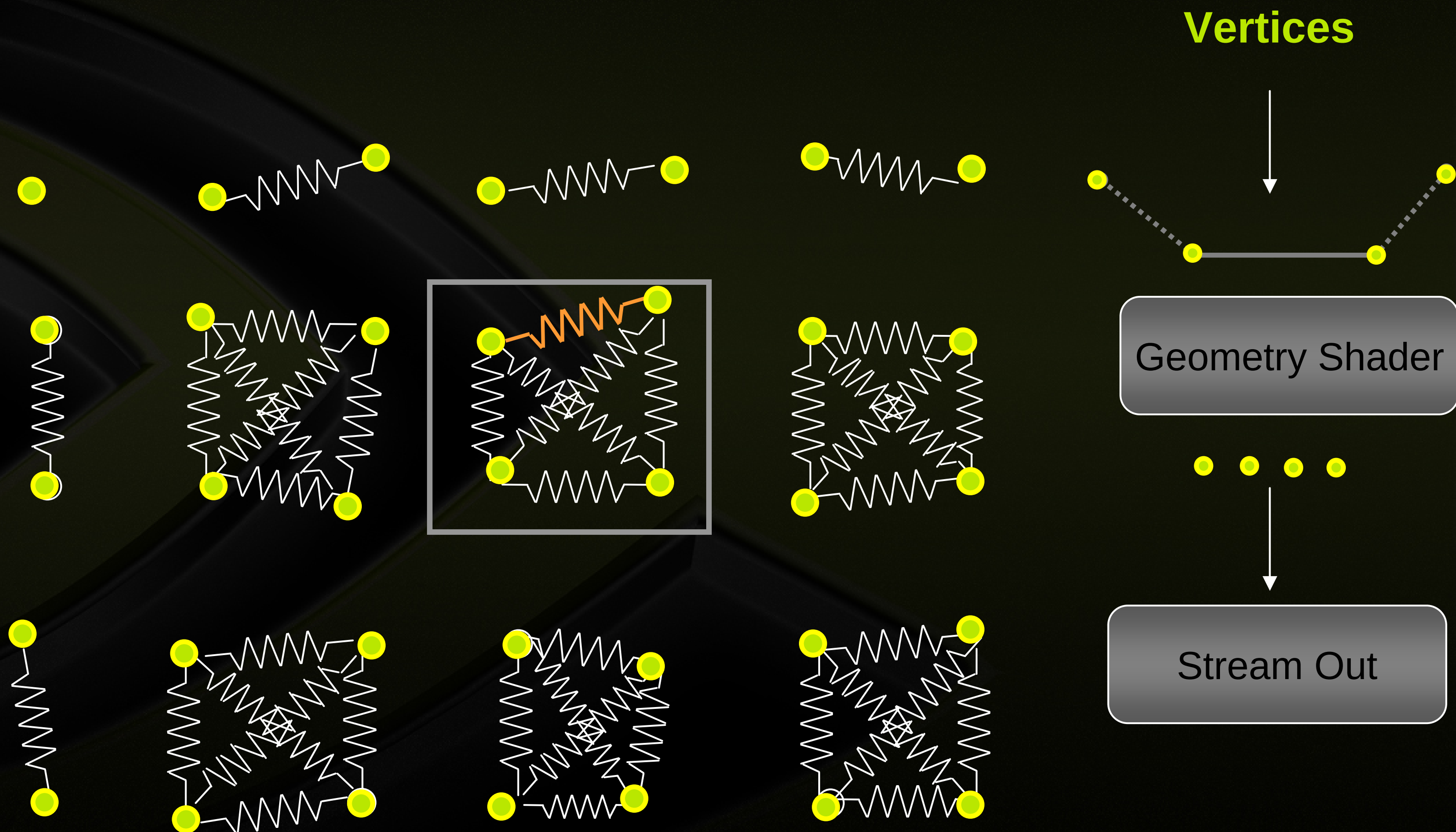
- **Particles stored in a vertex buffer**
  - DirectX9: particles would be stored in a texture
- **Computation in Geometry Shader and Vertex Shader**
  - DirectX9: computation in pixel shader
- **Synchronization (between passes) through Stream Out**
  - DirectX9: synchronization with writes to frame buffer and read from texture
- **Cloth cutting by adding triangles**
  - DirectX9: removing triangles
- **Fewer passes in DirectX10: 4 vs. 8 in DirectX9**

Apply Force: Vertex Shader



Each vertex gets a force applied to it

Satisfy distance constraints: Geometry Shader



The GS processes a set of vertices at a time
For each set we satisfy each of the spring constriants

Pseudo-Code: Initialization

- Create two vertex buffers to store the particles:
  - Vertex format is current position, old position, normal, etc.
  - One vertex buffer is used as input to the vertex shader
  - One vertex buffer is used as output to the geometry shader (Stream Output)
  - The two buffers are swapped after each rendering pass
- Create as many index buffers as there are batches of independent springs (4)
  - Each index buffer feeds the geometry shader with the right 4-tuples of particles
- Create an index buffer for rendering

Pseudo-Code: Simulation Loop

- Set a vertex shader that applies force
- Render to SO as a point list
- Swap vertex buffers
- For as many times as necessary:
  - For each batch of independent springs:
    - Set a geometry shader that applies distance constraints
    - Render to SO as an indexed triangle list with adjacency
    - Swap vertex buffers
  - Set a vertex shader that applies collision constraints
  - Render to SO as a point list
  - Swap vertex buffers

- Render to color buffer as indexed triangle list

Pseudo-Code: Simulation Loop

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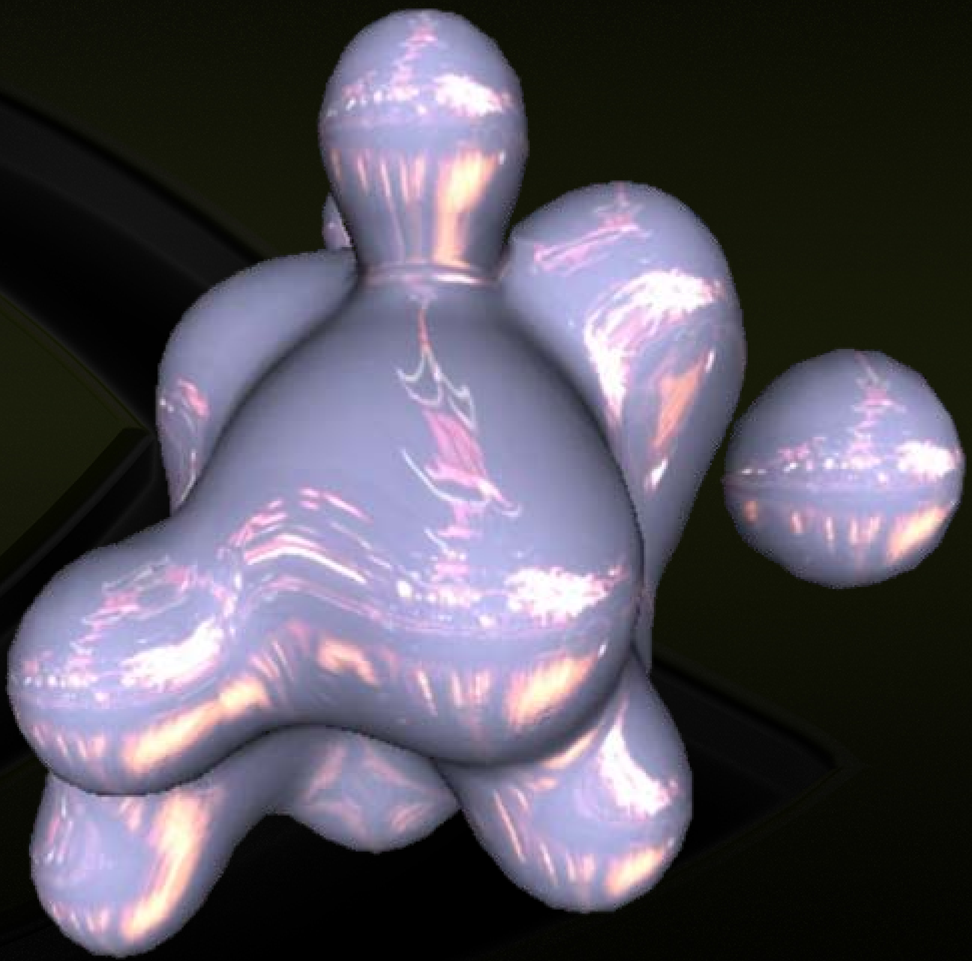
Apply forces

```
pass ApplyForces
    {
        SetVertexShader(CompileShader(vs_4_0, VS_ApplyForces()));
        SetGeometryShader(ConstructGSWithSO(CompileShader(vs_4_0, VS_ApplyForces()),
                                                        "State.x; Position.xyz"));
        SetPixelShader(0);
    }


void VS_ApplyForces(inout Particle particle, OldParticle oldParticle)
{
    // Apply Forces
    …
    // Integrate
    if (IsFree(particle))
        particle.Position += speedCoeff * diffPosition + force * TimeStep * TimeStep;
}
```

Metaballs on the GPU



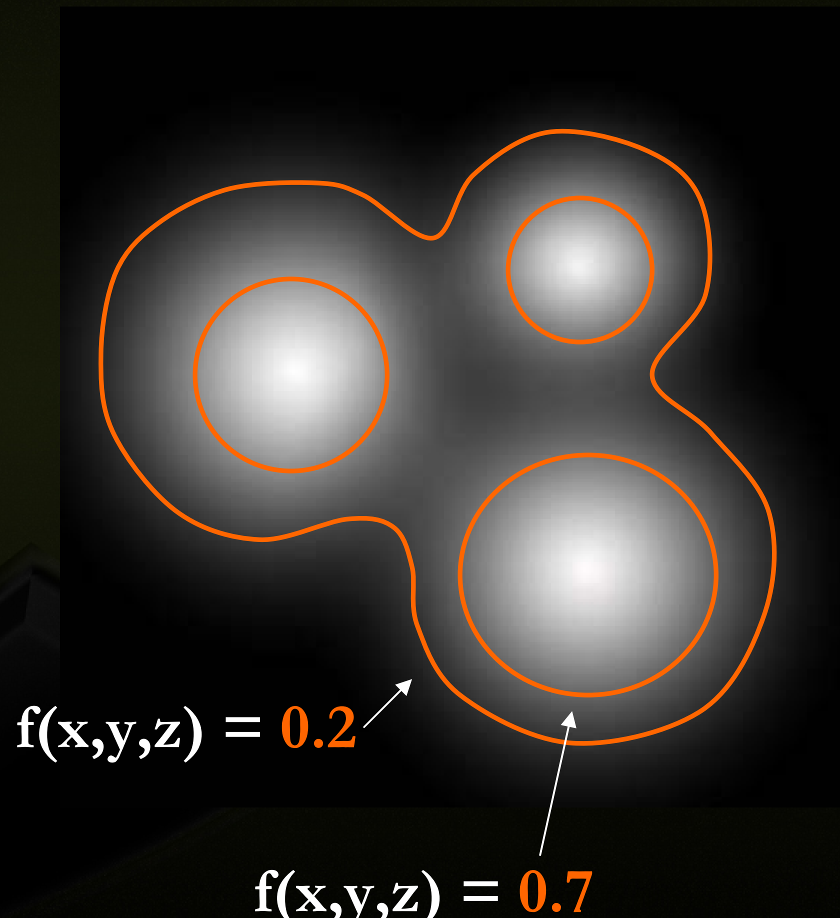
What are Isosurfaces?

- Consider a function
  - Defines a *scalar field* in 3D-space

$$f(x, y, z)$$

- *Isosurface* S is a set of points which satisfy the implicit equation

$$f(x, y, z) = const$$



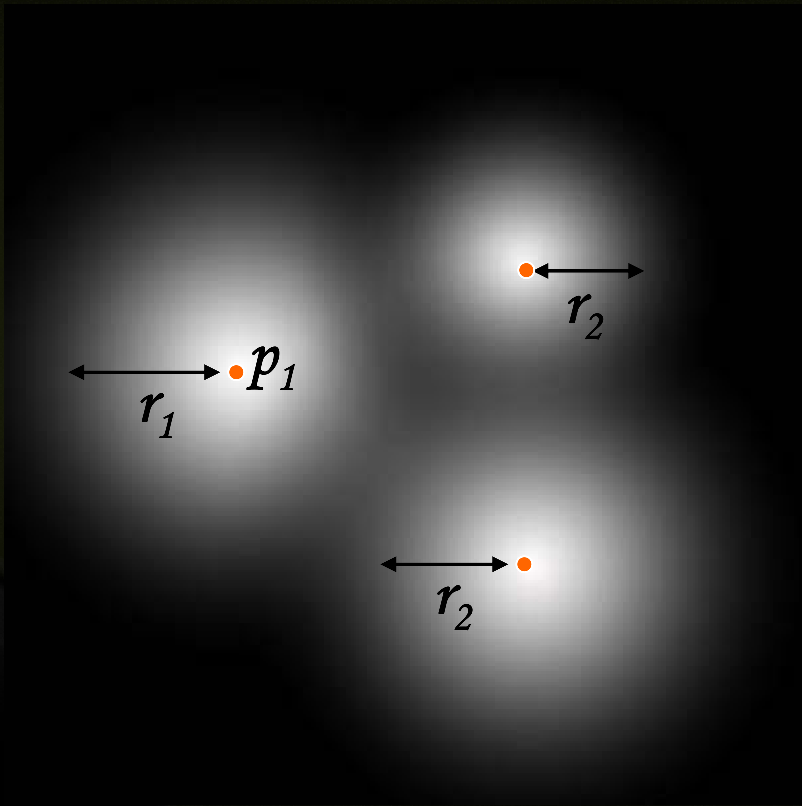
Metaballs

- A simple and interesting case
- Soft/blobby objects that blend into each other
  - Perfect for modeling fluids, explosions in games
- Use implicit equation of the form

$$\sum_{i=1}^{N} \frac{r_i^2}{\left\| \mathbf{x} - \mathbf{p}_i \right\|^2} = 1$$

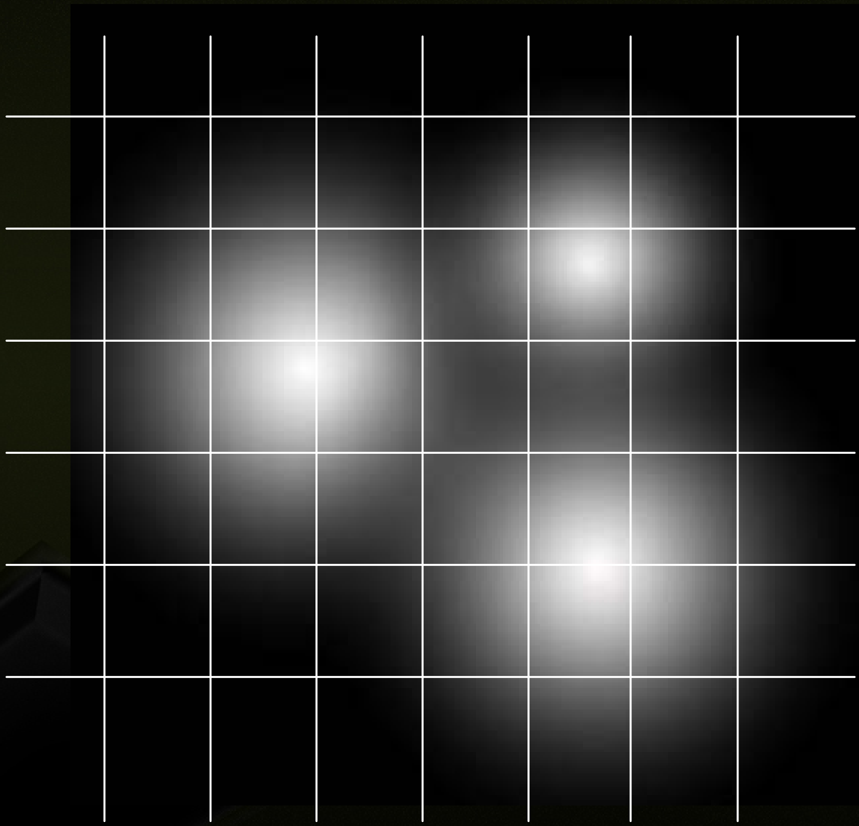
- Gradient can be computed directly

$$\mathbf{grad}(f) = -\sum_{i=1}^{N} \frac{2 \cdot r_i^2}{\left\| \mathbf{x} - \mathbf{p}_i \right\|^4} \cdot (\mathbf{x} - \mathbf{p}_i)$$



The Marching Cubes Algorithm

- To render an isosurface we can either ray trace it or polygonalize it
- Marching cubes: well-known method for polygonization of an isosurface
- Sample $f(x, y, z)$ on a cubic lattice



The Marching Cubes Algorithm

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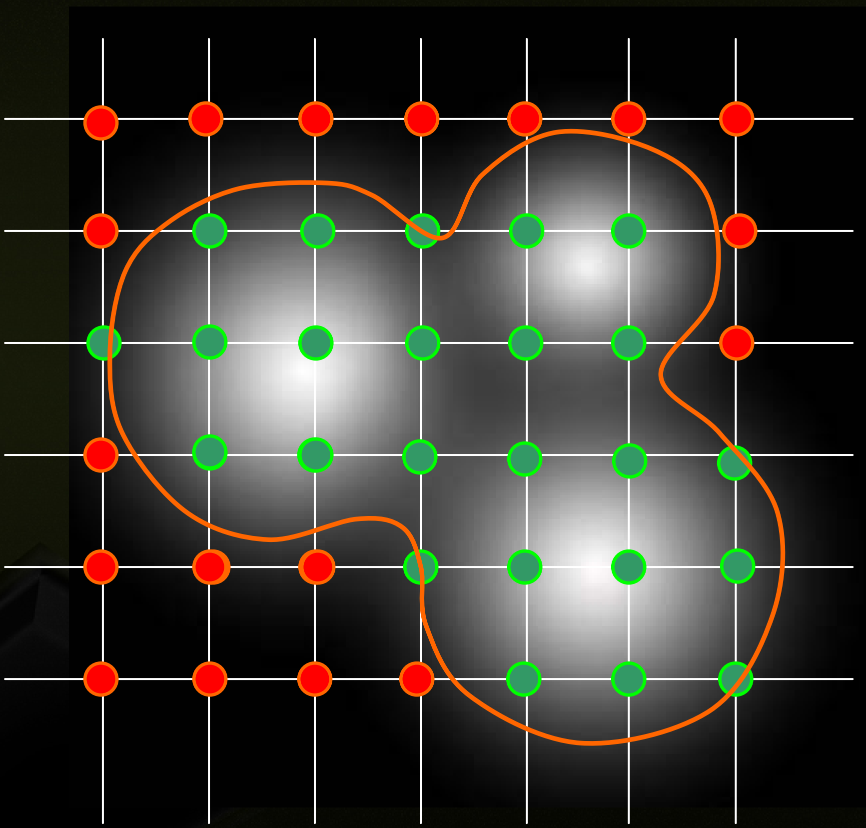
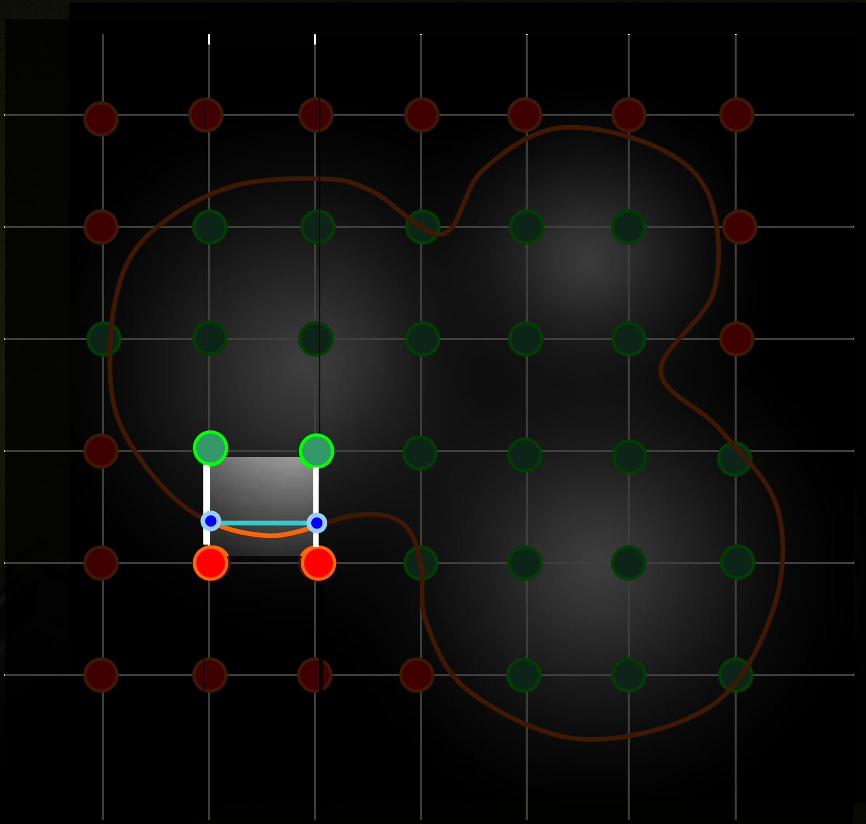
- Each vertex can be either "inside" or "outside" the isosurface`



$f(x,y,z) < 0.2$ $f(x,y,z) > 0.2$

The Marching Cubes Algorithm

- To render an isosurface we can either ray trace it or polygonalize it
- Marching cubes: well-known method for polygonization of an isosurface
- Sample $f(x, y, z)$ on a cubic lattice
- Each vertex can be either "inside" or "outside" the isosurface`
- Approximate the surface at each cube cell by a set of polygons



The surface crosses these edges since they span vertices that are on different sides of the surface

The Marching Cubes Algorithm

- To render an isosurface we can either ray trace it or polygonalize it
- Marching cubes: well-known method for polygonization of an isosurface
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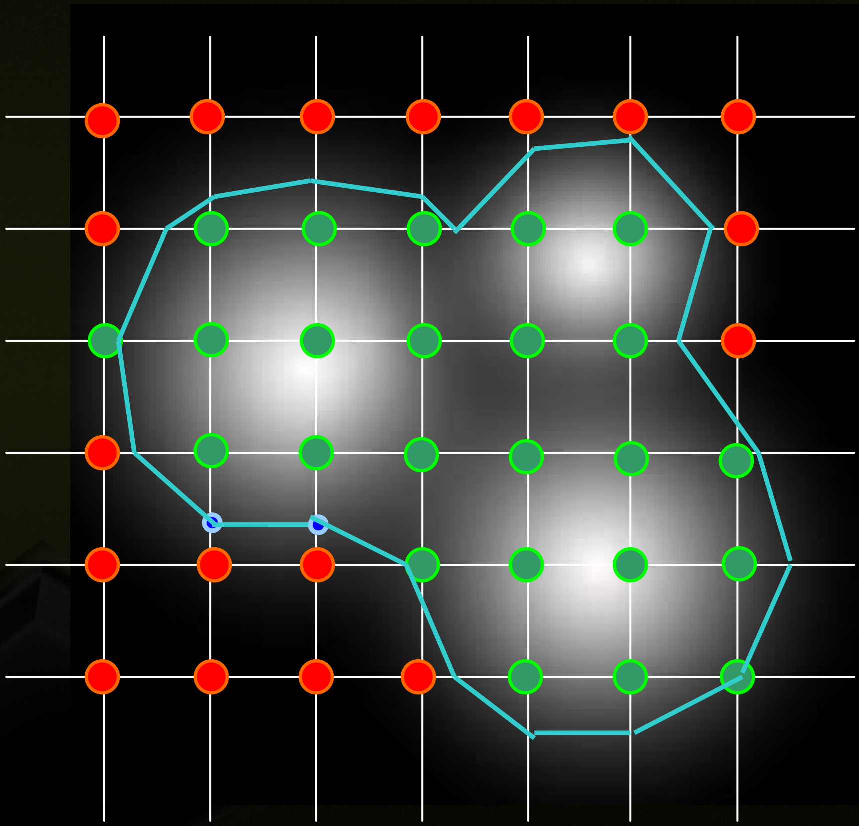
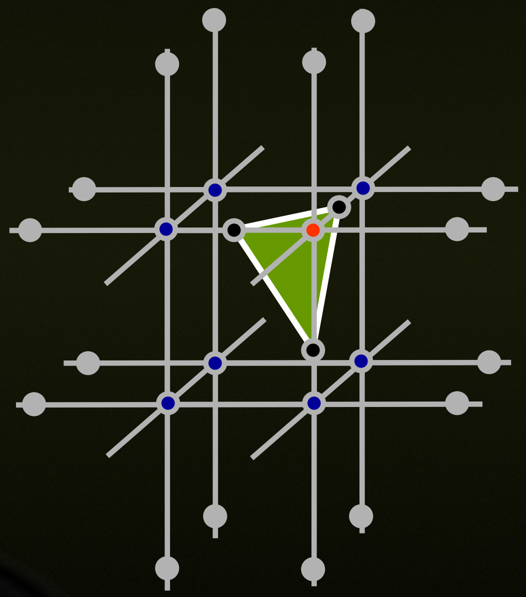
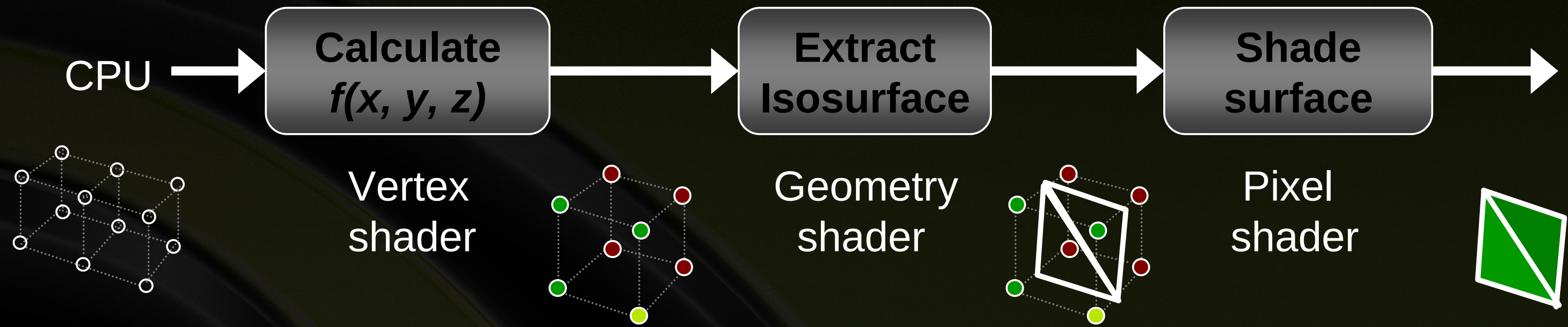


The Marching Cubes Algorithm

- For each cubic cell:
  - If any edge connects a vertex that is in and one that is out, then the isosurface intersects that edge
  - Estimate where isosurface intersects edge by linear interpolation
  - Emit variable number of triangles depending on how many edges the surface intersects

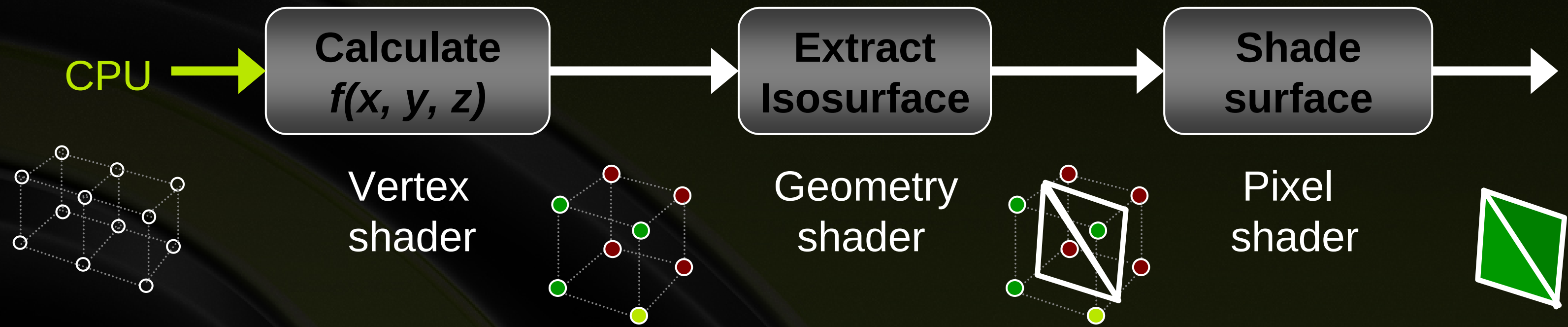


Implementation - Pseudo-Code



- **App feeds a GPU with a grid of vertices**
- **VS transforms grid vertices and computes f(x, y, z), feeds cubes to GS**
- **GS processes each cube in turn and emits triangles**

Implementation - Pseudo-Code



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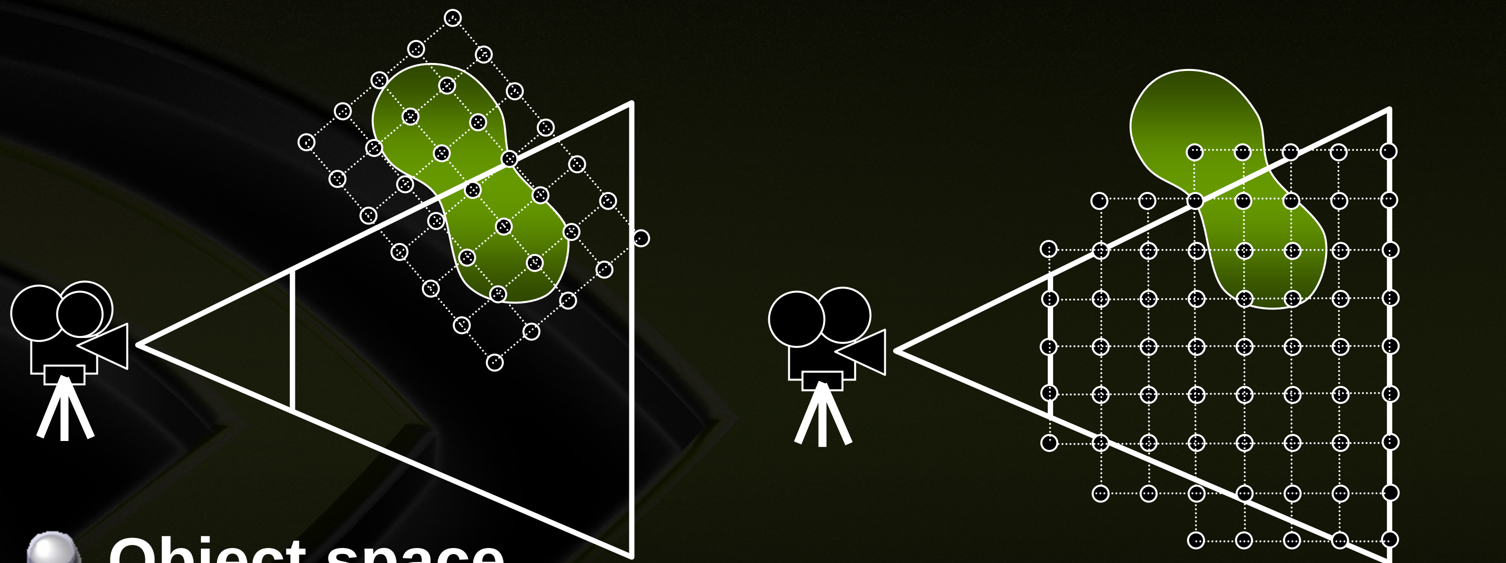
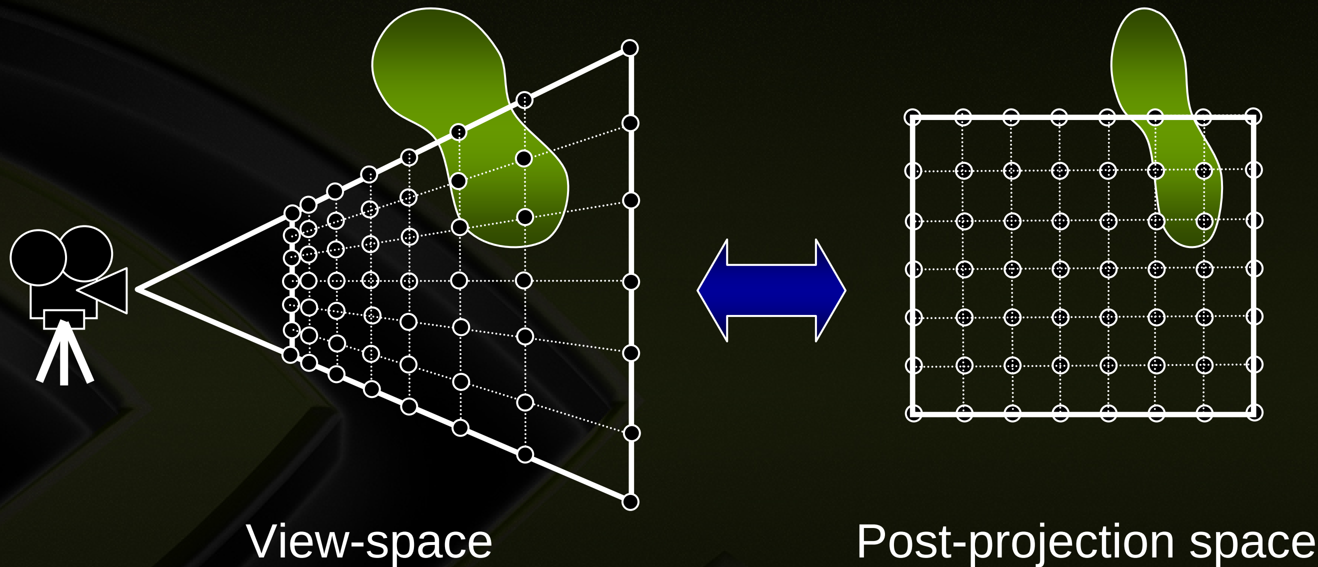
- **GS processes each cube in turn and emits triangles**

Tessellation space



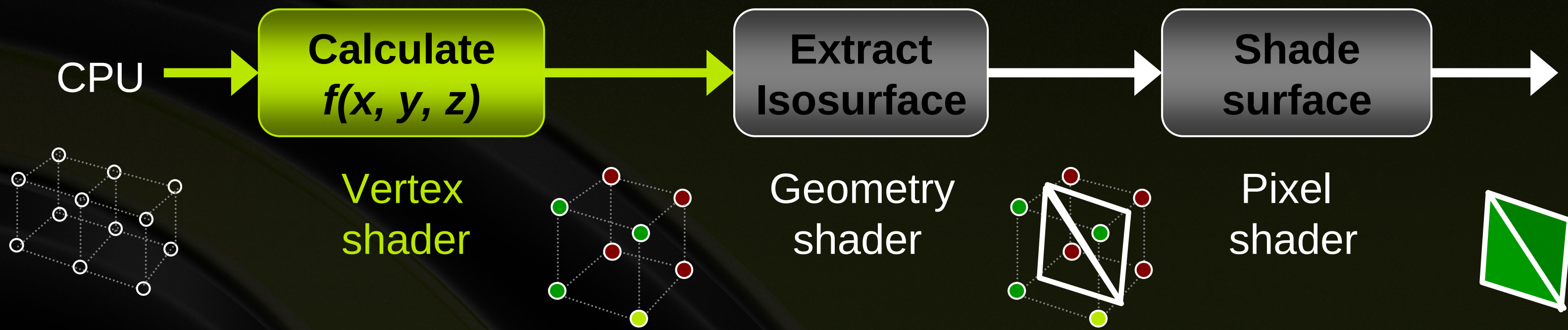
- Object space
  - Works if you can calculate BB around your metaballs
- View space
  - Better, but sampling rate is distributed inadequately

Tessellation in post-projection space



- Post-projective space
  - Probably the best option
  - We also get LOD for free!

Implementation - Pseudo-Code



- App feeds a GPU with a grid of vertices
- **VS transforms grid vertices and computes f(x, y, z), feeds cubes to GS**
- GS processes each cube in turn and emits triangles

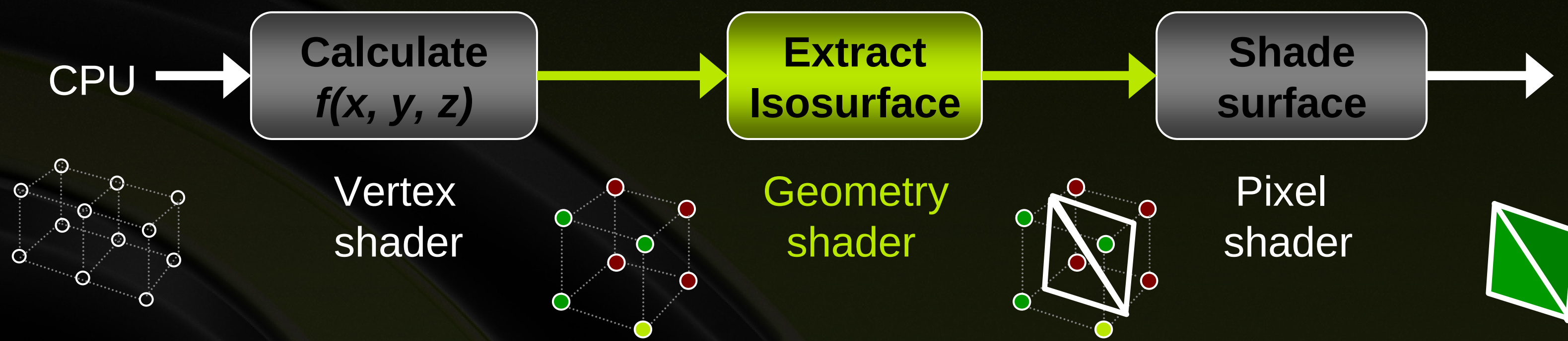
Vertex shader

- **Calculate the following values for each vertex v:**
  - **The Scalar field value** $f(v) = \sum_{i=1}^{N} \frac{r_i^2}{\left\| v - \mathbf{p}_i \right\|^2}$
  - **A flag specifying whether the vertex is inside the field**

    $$Field = f(v) > 1 ? 1 : 0$$

  - **The normal of the scalar field**
  - **The projected position of the vertex**

Implementation - Pseudo-Code



- App feeds a GPU with a grid of vertices
- VS transforms grid vertices and computes f(x, y, z), feeds cubes to GS
- **GS processes each cube in turn and emits triangles**

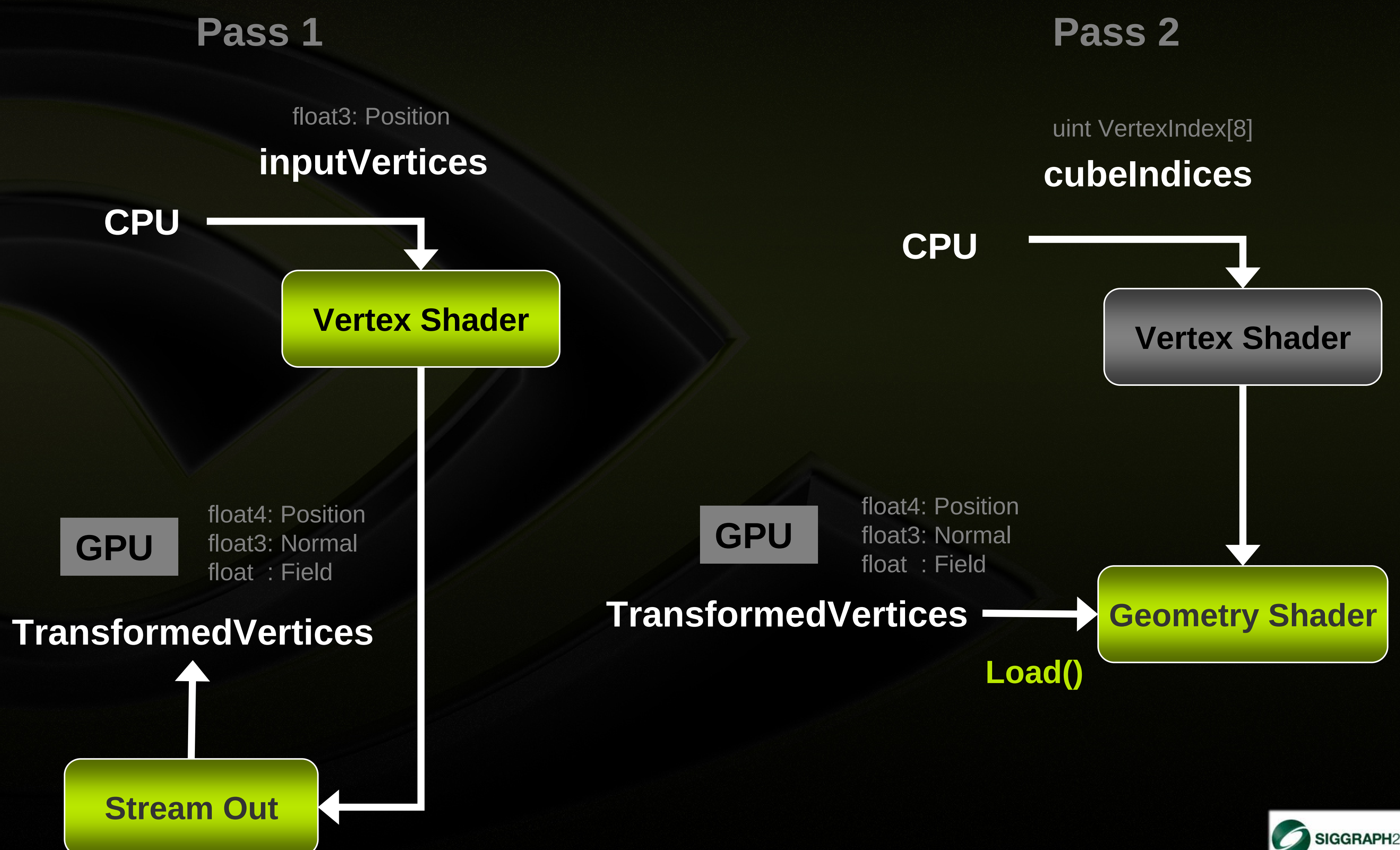
How do we get 8 vertices in the GS

- We can read the value at a given index inside a vertex buffer directly from the Geometry Shader:

```
vertexValue = VertexBuffer.Load(index);
```

- Can issue 8 such statements to fetch all vertices for a given cube

How do we get 8 vertices in the GS



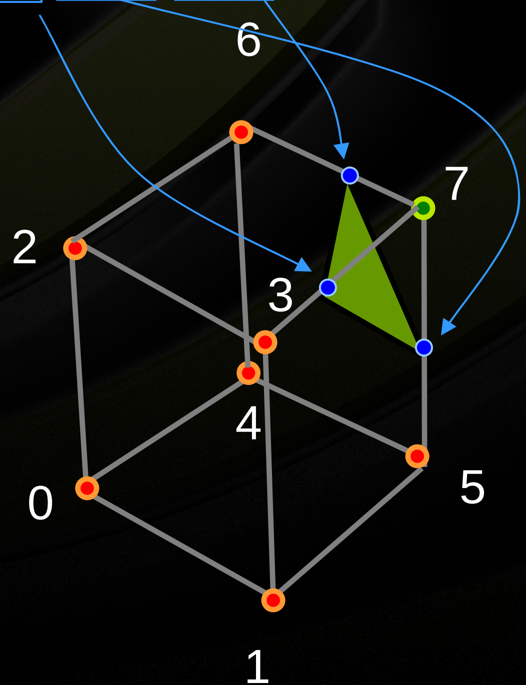
Geometry Shader

```
[MaxVertexCount(16)]
void GS_TesselateCube(point CubePrimitive In[1],inout
     TriangleStream<SurfaceVertex> Stream)
{
     //1. Construct index and load field data into temporaries
     uint index = 0;

     for (uint i = 0; i<8; i++)
     {
         //construct bit field with a bit set for every vertex inside surface
         index |= SampleDataBuffer.Load( In[0].VertexIndex[i] ).Field > 1 ? 1 : 0;
         index <<= 1;
     }
```

Edge table construction

```
// StripCount contains number of triangle strips to generate for particular index value
const uint2 StripCount[256] = {
          { 0,                                                  //index = 0
            1,                                                  //index = 1
            // …
    };
// EdgeTable stores precomputed vertex indices for each cube edge which needs to be
    interpolated
const uint2 EdgeTable[256][16] = {
          { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 }, //index = 0
          { 7, 3, 7, 5, 7, 6, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 }, //index = 1
          // …
    };
```



Index = 00000001,
i.e. vertex 7 is “inside”

Geometry Shader

```
    // 2. Generate triangle strips according to "index" value

    // Get number of triangle strips for this index
    uint NumStrips = StripsCount[index];

    // Emit that many triangle strips...
    uint j = 0;
    for (uint i = 0; i<NumStrips; i++)
    {
        while (1)
        {
            uint2 edge = EdgeTable[index][j++];
            if (edge.x == edge.y) {    // edge.x == edge.y indicates a restart
                Stream.RestartStrip();
                break;
            }

            Stream.Append( CalcIntersection(
                  SampleDataBuffer.Load( In[0].VertexIndex[edge.x] ),
                  SampleDataBuffer.Load( In[0].VertexIndex[edge.y] )
                         ) );
        }
    }
}
```

Metaballs

- The Geometry Shader can be efficiently used for isosurface extraction

- Allows for class of totally new cool effects
  - Animating organic forms
  - Modeling fluid like behavior in games (particle systems which model fluids)
  - Add noise to create turbulent fields

- Marching cubes can also be used for visualization of medical data

Conclusions

- DirectX10 offers new functionality that enables the GPU to run algorithms that used to only run on the CPU
  - Marching Cubes
- Increased flexibility allows for easier and more efficient implementation for other applications like GPGPU
  - Cloth
  - Fins generation

Acknowledgments

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Questions?

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