Feed Forward Non-Pinhole Rendering

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Motivation

- Graphics, visualization, and vision almost exclusively use pinholes
  - Pinhole restriction is limiting
- Recent work shows that non-pinholes can provide support for graphics and visualization.
- Misconception about non-pinholes
  - “Rendering is slow, ray tracing is needed”
- We argue that one can render with non-pinholes efficiently, in feed-forward fashion, with hardware support

Talk Outline

- Overview of prior non-pinhole cameras by others
- Overview of prior non-pinhole cameras by Purdue CVGLAB
- Discuss 3 major challenges of feed-forward non-pinhole rendering
- Describe general solutions to the challenges

Prior non-pinholes by Others

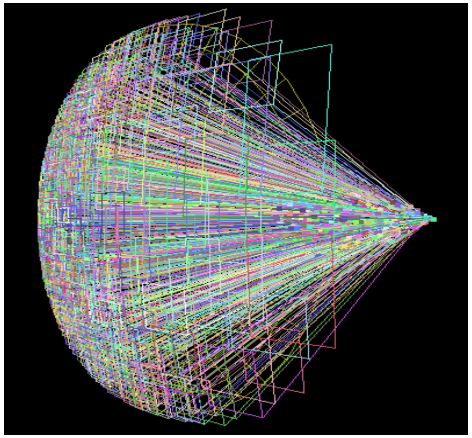
- Light field & lumigraph
  - 2-D array of pinhole cameras
- Multiple center of projection images
  - Vertical slit moving along user designed path
- Layered depth images
  - Planar pinhole camera with more than one sample on a ray

- *All of these non-pinholes are inefficient as they require rendering the scene multiple times*

Prior non-pinholes by CGVLAB

- Sample-based camera (SBC)
  - A set of binary space partitioning (BSP) trees storing planar pinhole cameras at their leaves
  - Used to render high quality reflections at interactive rates

Sample Based camera model

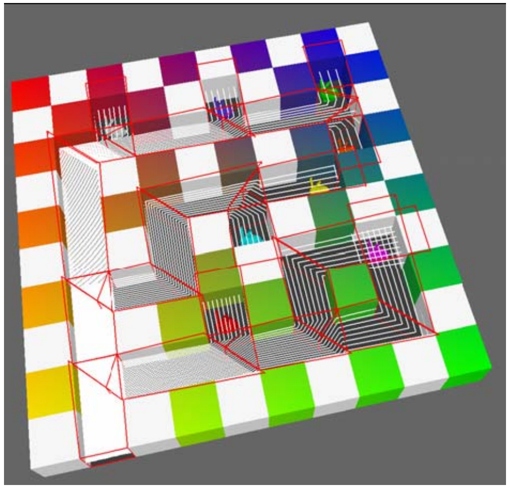


Sample SBC image

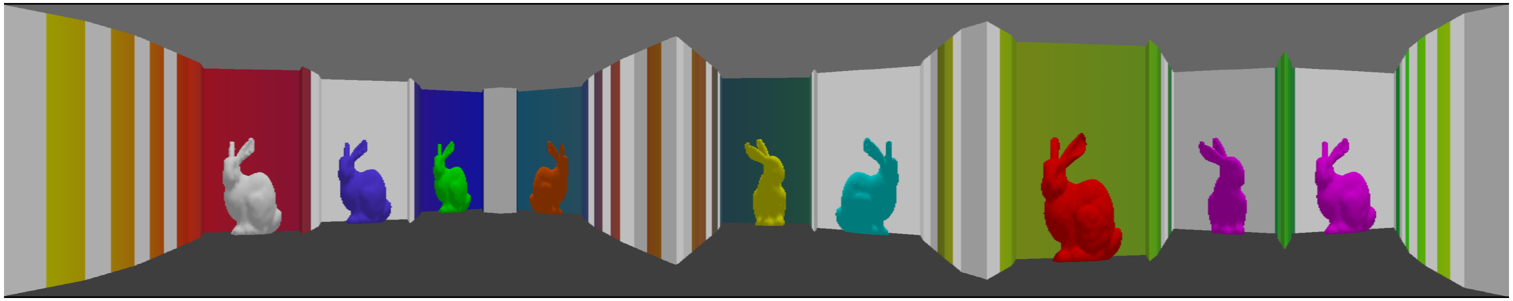
Prior non-pinholes by CGVLAB

- Graph camera (GC)
  - A graph of non-pinholes producing a single-layer image
  - Frusta are split, bent, and merged to sample entire scene

Graph camera model



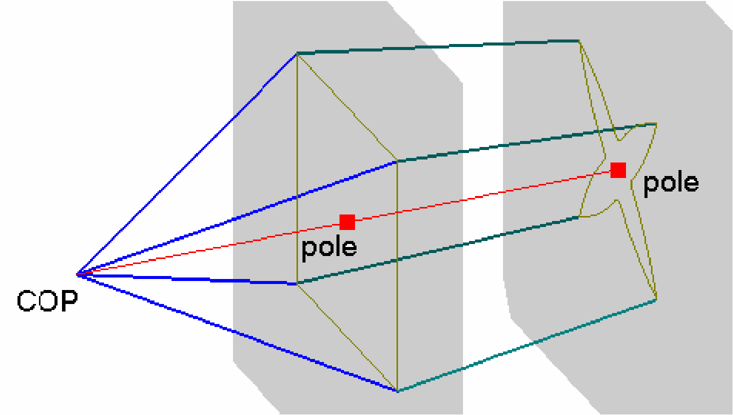
Sample Graph camera image



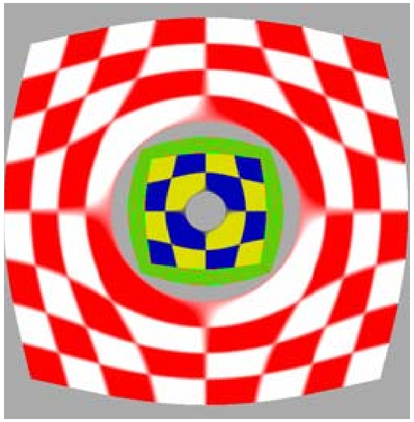
Prior non-pinholes by CGVLAB

- Single-pole occlusion camera
  - A planar pinhole with a 3-D radial distortion

SPOC camera model



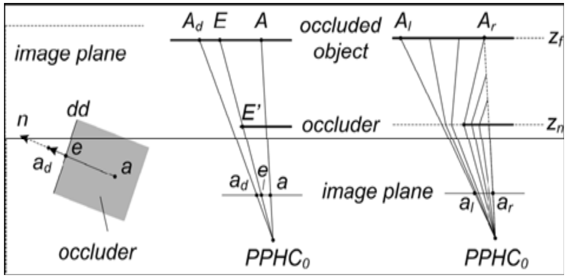
Sample SPOC image



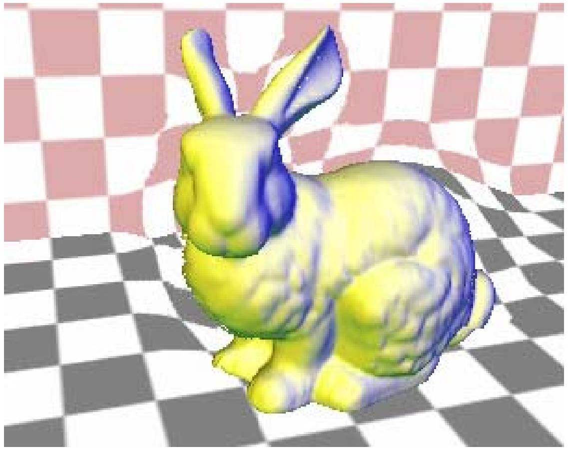
Prior non-pinholes by CGVLAB

- Depth discontinuity occlusion camera
  - A planar pinhole with 3-D distortion specified per pixel

DDOC camera model



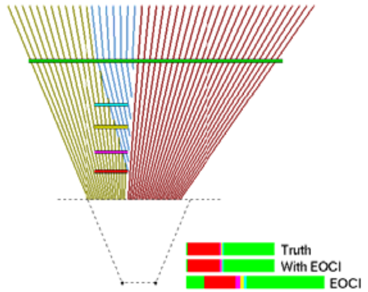
Sample DDOC image



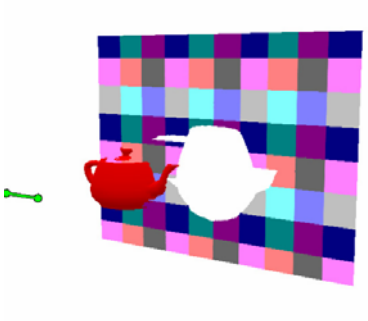
Prior non-pinholes by CGVLAB

- Epipolar occlusion camera
  - Generalizes view*point* to view*segment*

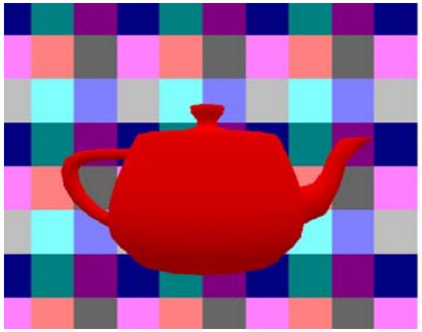
EOC rays on a row with 4 occluders



Samples captured by EOC



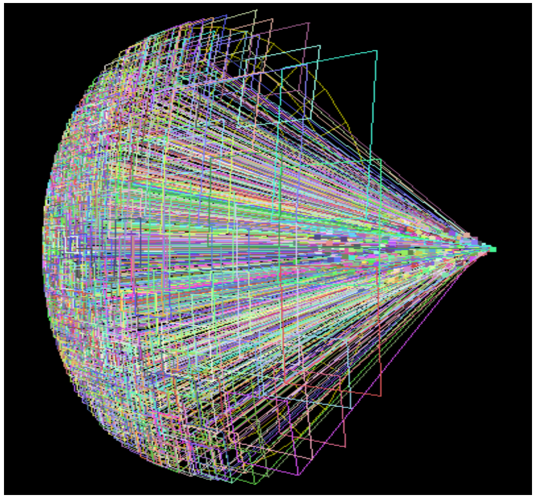
Sample EOC image



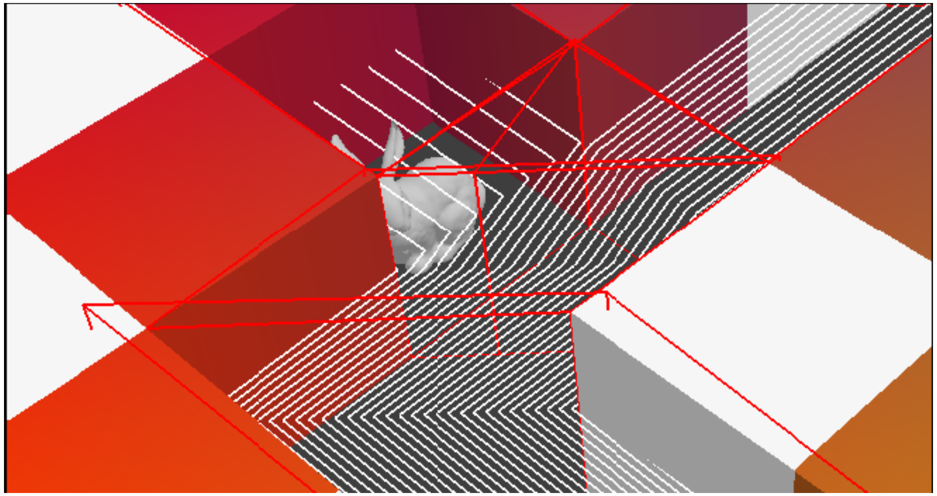
Challenge 1: complex projection

- Problem: given a 3-D point, find frustum (frusta) that contain(s) it

Sample Based Camera

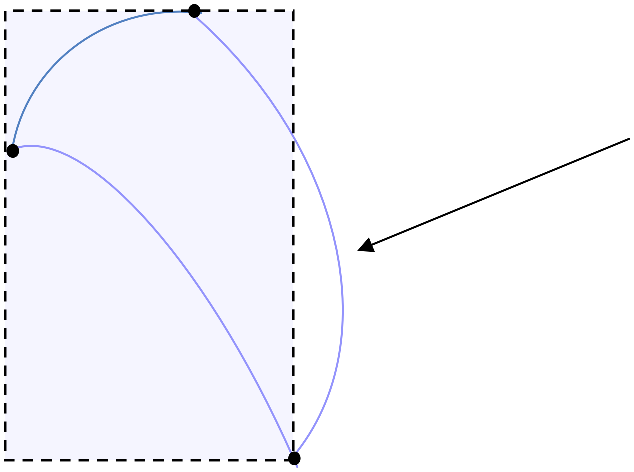


Graph Camera



Challenge 2: footprint estimation

- Problem: given a triangle & a non-linear projection, find projected triangle footprint defining pixels where to rasterize



Problem: Bounding box does not encapsulate entirety of pixels inside of distrorted triangles

Challenge 3: non-linear rasterization

- Problem: Given a non-pinhole camera, a triangle, and a pixel *p*, find rasterization parameter value *p*

Solution: Multi-pinhole Approach

- Addresses the complex projection challenge
- Use your favorite space partitioning scheme (e.g. grid, octree, BSP trees, etc.) to find non-pinhole frustum that contains 3-D point
- Examples: SBC, GC
  - No footprint or non-linear rasterization problems since individual cameras are pinholes
  - Each pinhole camera is rendered with a traditional feed-forward pipeline

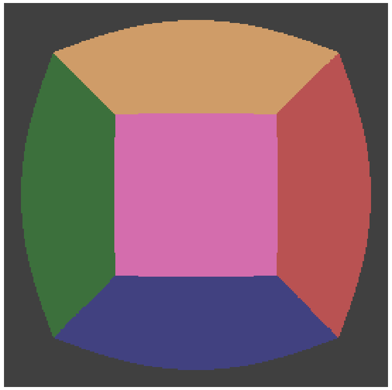
Solution: Subdivision Approach

- Addresses footprint estimation and non-linear rasterization challenges
- Subdivide triangle sufficiently to make linear rasterization an acceptable approximation
  - Takes advantage of programmability at primitive level exposed by recent hardware

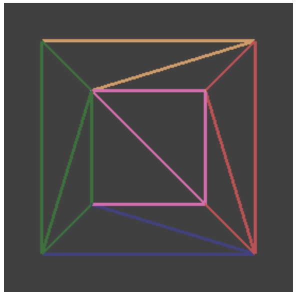
Solution: Subdivision Approach

- Our implementation uses a geometry shader to perform a user specified number of subdivisions per triangle
- Geometry Shader Outline:
  - Given triangle
    - Find subdivision factor k
    - Subdivide into k^2 subtriangles
    - For each subtriangle
      - Project triangle
      - Issue projected triangle

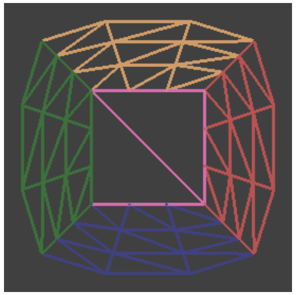
Solution: Subdivision Approach Images



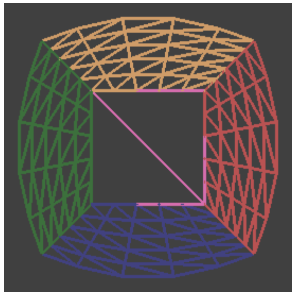
Reference SPOC
Image of Cube



K=1



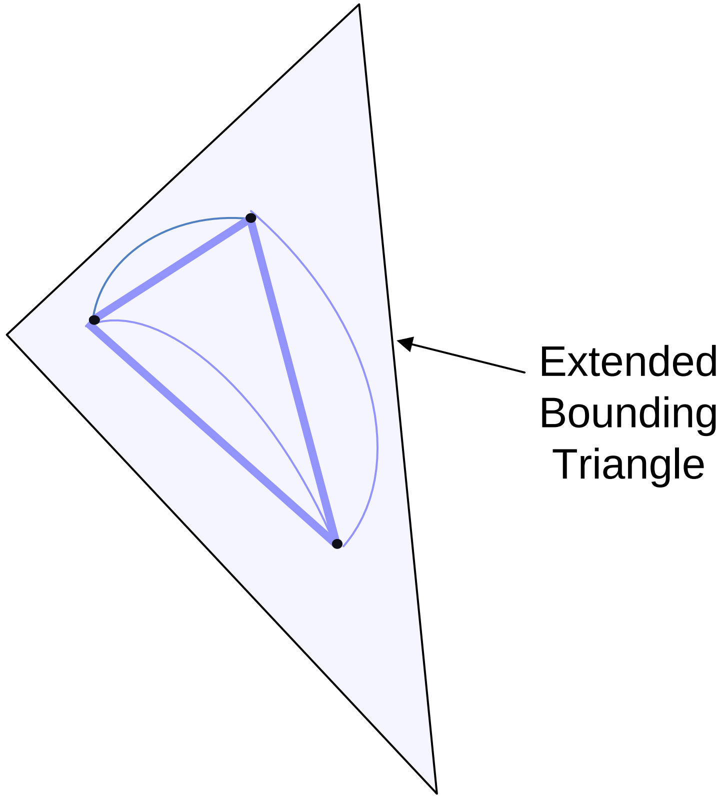
K=3



K=5

Solution: Non-linear Rasterization Approach

- Addresses footprint estimation and non-linear rasterization challenges
- Rasterization is performed directly in non-pinhole image domain
- A bounding triangle is calculated using a vertex shader for the curved edges of the distorted triangle
- Size of the bounding triangle determined by user defined extension factor

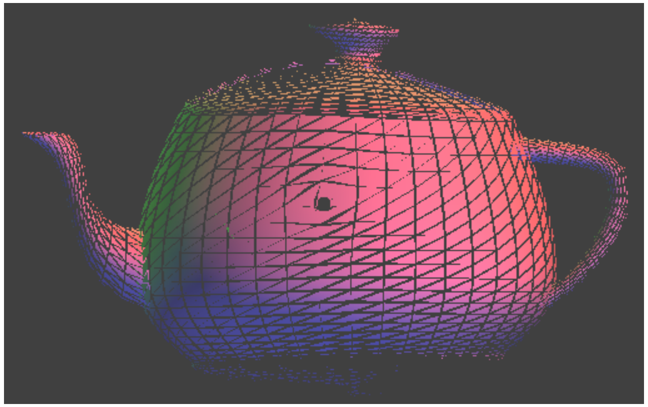


Algorithm overview

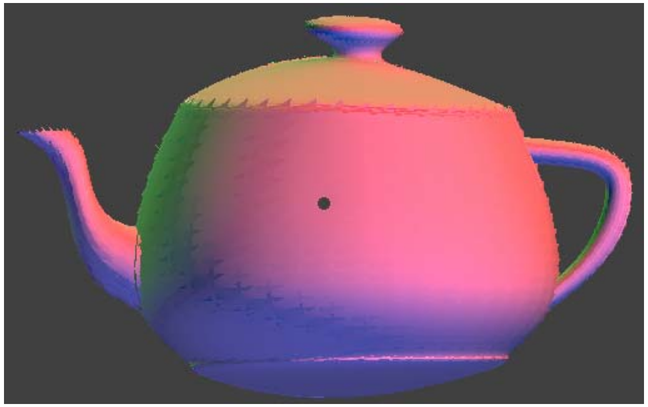
- For each pixel in footprint
  - Find non-pinhole camera ray
  - Intersect ray with 3-D triangle
  - If inside triangle & visible
    - Shade on triangle plane

Visualization of triangle extension

No Extended Triangles



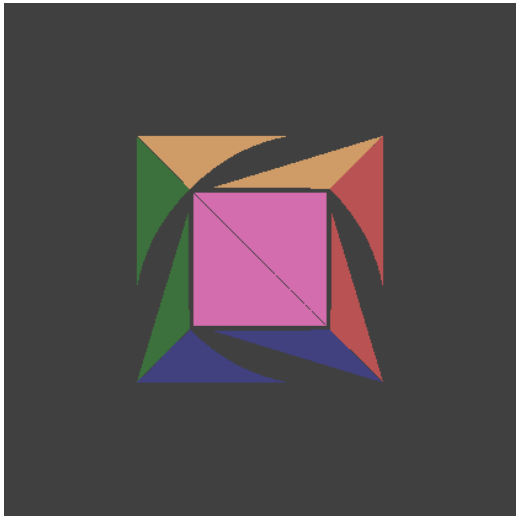
Extension Factor of 3.0



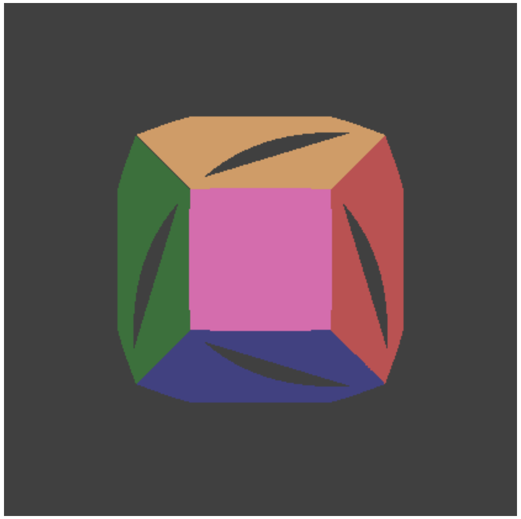
Zoom View

Visualization of triangle extension

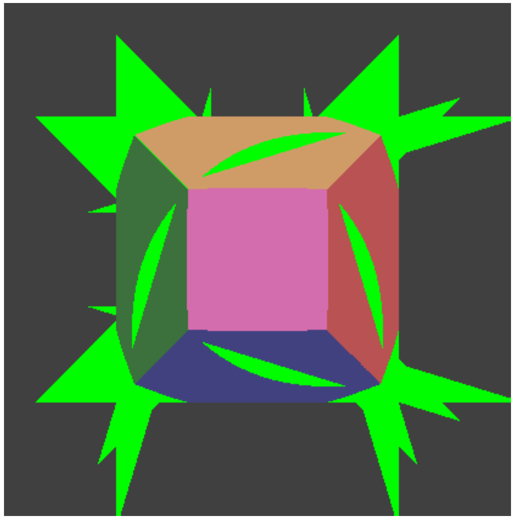
No Extended Triangles



Extension Factor of 1.0



Overdrawn pixels highlighted in green



Conclusions

- Modern GPUs are sophisticated and fast enough to render with non-pinholes
- Just make sure the non-pinhole model has a fast projection function
- Build your own non-pinholes

References

- [PSM06] Popescu V., Sacks E., Mei C.: Sample-Based Cameras for Feed-Forward Reflection Rendering, *IEEE Transactions on Visualization and Computer Graphics*, 2006
- [RPA08] Rosen P., Popescu V., Adamo-Villani N.: The Graph Camera, *Purdue University Technical Report CSD TR #08-005, 2008*
- [RP08] Rosen P., Popescu V.: The Epipolar Occlusion Camera, In *Proc. of ACM Symp.I3D and Gaming,* 2008
- [PA06] POPESCU, V. and D. ALIAGA: Depth Discontinuity Occlusion Camera, In *Proc. of ACM Symp.I3D and Gaming,* 2006.
- [MPS05] Mei C., Popescu V., Sacks E.: The Occlusion Camera, *Computer Graphics Forum, Eurographics 2005*.

Geometry Shader

```
TRIANGLE void SPOCConstructionM2GS(AttribArray<VertexDataOutput> vo,
  uniform PHCamera phc, uniform SPOCParameters spocParameters) {
        // figure out the subdivision factor
        int k = FindSubdivisionFactor(vo, spocParameters, phc);
        int kmax = 5;
        k = clamp(k, 1, kmax);

        float3 bcs[3]; // barycentric coordinates
        int n = k*(k+1); n /= 2;
        int nmax = kmax*(kmax+1); nmax /= 2;
        int i = 0;
        int j = 0;
        for (int h = 0; h < nmax && h < n; h++) {
                bcs[0] = GetBCS(i, j, k);
                bcs[1] = GetBCS(i+1, j, k);
                bcs[2] = GetBCS(i+1, j+1, k);
                emitVertex(InterpolateVertexDataThenDistort(vo, bcs[0], spocParameters, phc));
                emitVertex(InterpolateVertexDataThenDistort(vo, bcs[1], spocParameters, phc));
                emitVertex(InterpolateVertexDataThenDistort(vo, bcs[2], spocParameters, phc));
                restartStrip();
                if (j < i) {
                        bcs[0] = GetBCS(i, j, k);
                        bcs[1] = GetBCS(i+1, j+1, k);
                        bcs[2] = GetBCS(i, j+1, k);
                        emitVertex(InterpolateVertexDataThenDistort(vo, bcs[0], spocParameters, phc));
                        emitVertex(InterpolateVertexDataThenDistort(vo, bcs[1], spocParameters, phc));
                        emitVertex(InterpolateVertexDataThenDistort(vo, bcs[2], spocParameters, phc));
                        restartStrip();
                        j++;
                }
                else {
                        i++;
                        j = 0;
                }
```