NVScene

Rendering Worlds with Two Triangles with raytracing on the GPU in 4096 bytes

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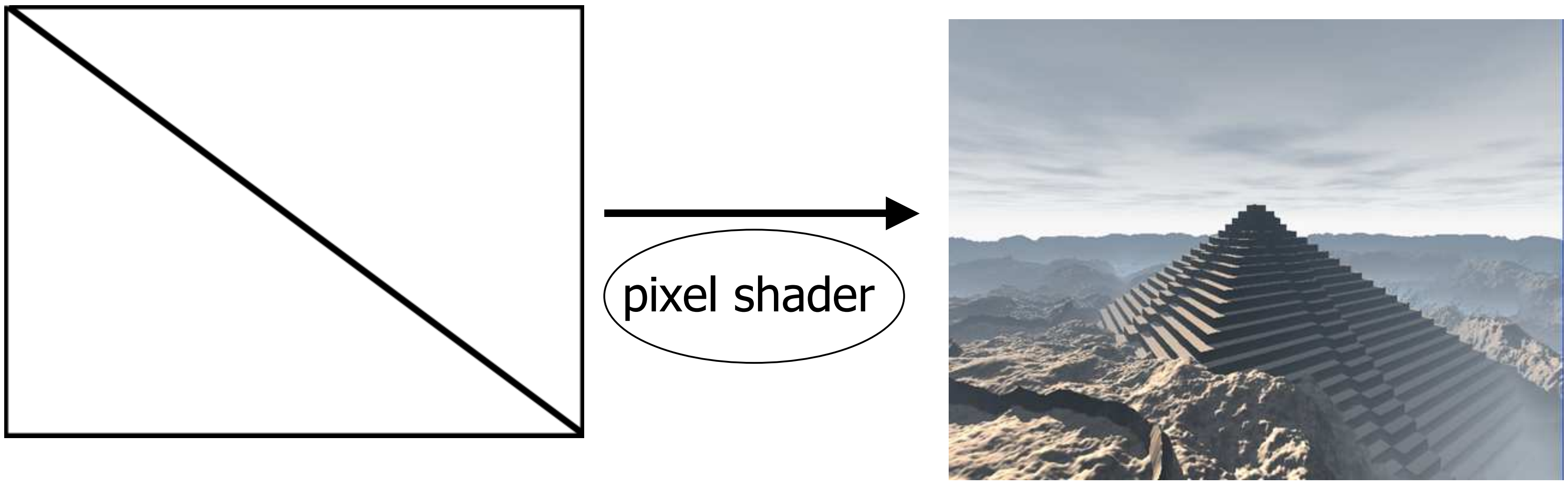
A bit of context

- Amazing progression in raw GPU power.
- Shaders 3 and 4 flexible enough for
  - Experimenting with new techniques.
  - Revival of some old-school effects (at a higher quality than ever).
- Unexpected benefits:
  - Easy to set up and very compact code.
  - 4k demo coders have jumped into it.

A bit of context

• The idea: draw two triangles that cover the entire screen area, and invoke a pixel shader that will create an animated or static image.

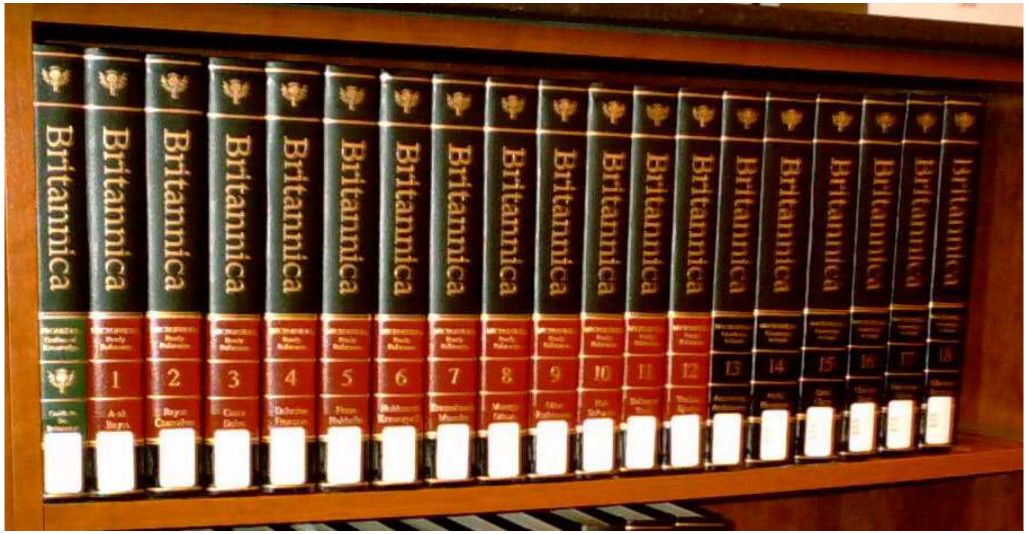


• Make the complete demo self-contained in no more 4096 bytes (that includes the “engine”, music, shaders, animations, textures and everything).

A bit of context

- How much is a kilobyte ?

This is the size of a 4 kbytes production

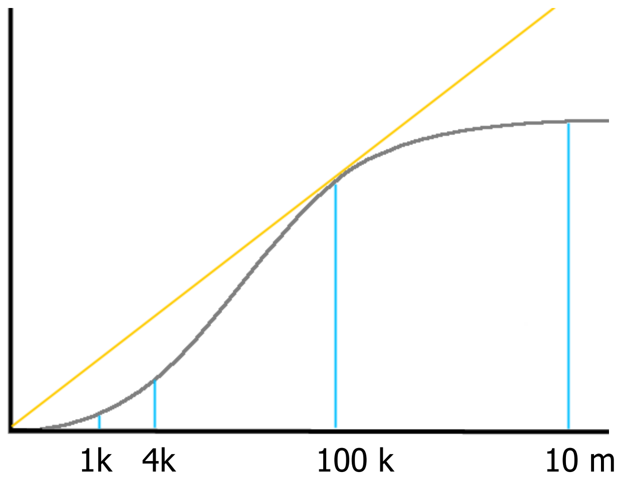


This is the size of a 64 megabytes demo or video

A bit of context

• Probably not a fair comparison (we cannot blame demo coders for being lazy compared to intro coders).

• The “visual_beauty” is not a linear function of the size in kilobytes.



• Speculation: With current technology, the optimal “vibes per kilobyte” (aka result/effort ratio, or “wow factor”) is arround 100 kb productions.

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- Rendering with distance fields

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Old-school effects are back

• Filling the screen with a shader, and producing an image or animation from it, only works for algorithms and effects that follow this pattern:

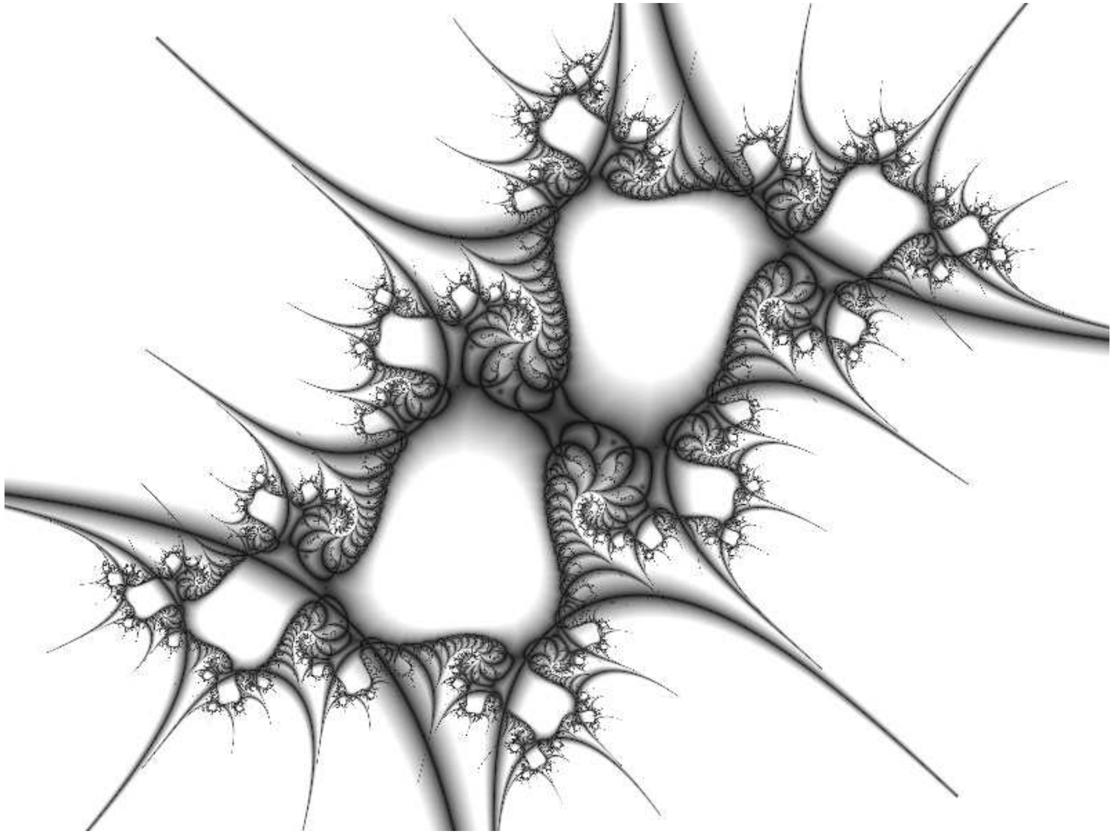
```
for( each pixel p )
{
    outputColor = doSomething( p );
}
```

• This doesn't naturally extend to effects that need to do operations accross pixels (gather and scatter operations). Multipass techniques can be used, but

- it might actually be slower than doing it on the CPU
- it's not elegant
- it's not very compact for 4k demos

Old-school effects are back

- Julia and Mandelbrot sets (the “hello world” of gfx programming)



Old-school effects are back

- Plane deformations

Oldschool software version

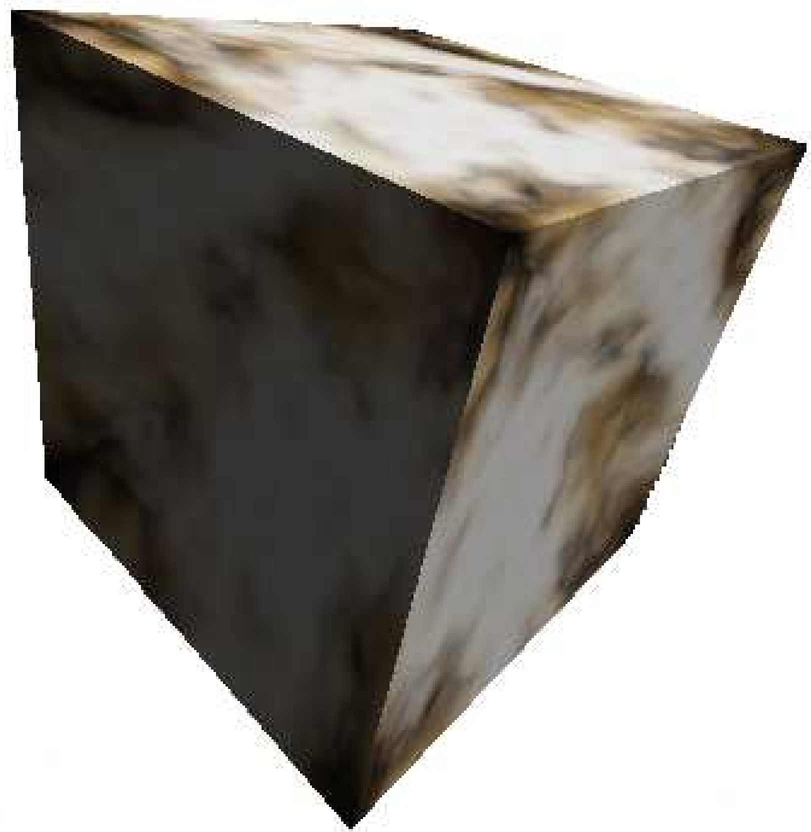
```
for( int i=0; i<numPixel; i++ )
{
    const uint16 offset = magicLUT [i] + time;
    buffer[i] = texture[ offset & 0xffff ];
}
```

Pixel shader version

```
void main( void ) //for( each pixel p )
{
    vec2 offset = magicFormula(p, time);
    gl_FragColor = texture2D(texture, offset);
}
```

Old-school effects are back

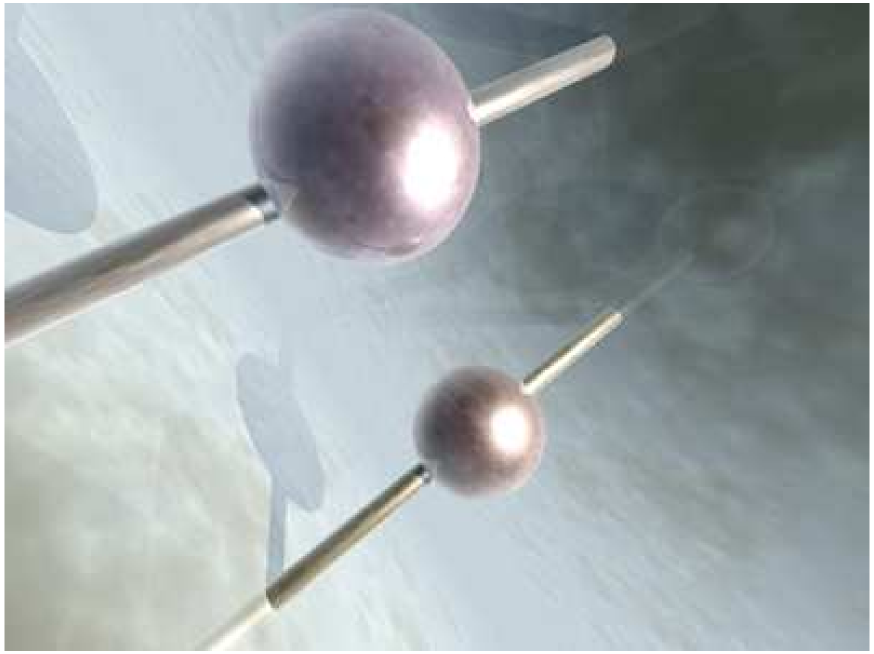
- Others?
  - Rasterizers!
    - Vertex transformation
    - Triangle rasterization
    - Not perspective corrected
  - Metaballs
  - Plasmas
  - Raytracing



Old-school effects are back

- Whitted raytracing of simple scenes/primitives
  - A classic in demoscene
  - With fake analytic Ambient Occlusion

Chocolux, by Auld, 2007 [1 kbyte demo]



Kinderpainter, by rgba, at BCN 2006 [4k kbytes demo]

Old-school effects are back

```
#include <windows.h>
#include <GL/gl.h>
#include <GL/glext.h>

char *vsh="\
varying vec3 s[4];\
void main(){\
gl_Position=gl_Vertex;\
s[0]=vec3(0);\
s[3]=vec3(sin(abs(gl_Vertex.x*.0001)),\
cos(abs(gl_Vertex.x*.0001)),0);\
s[1]=s[3].zxy;\
s[2]=s[3].zzx;}";

char *fsh="\
varying vec3 s[4];\
void main(){\
float t,b,c,h=0;\
vec3 m,n,p=vec3(.2),d=normalize(.001*gl_FragCoord.rgb-p);\
for(int i=0;i<4;i++){\
t=2;\
for(int i=0;i<4;i++){\
b=dot(d,n=s[i]-p);\
c=b*b+.2-dot(n,n);\
if(b-c<t)if(c>0){m=s[i];t=b-c;}\
}\
p+=t*d;\
d=reflect(d,n=normalize(p-m));\
h+=pow(n.x*n.x,44.)+n.x*n.x*.2;\
}\
gl_FragColor=vec4(h,h*h,h*h*h*h,h);}";
```

Source code of chocolux, by Auld (link with Crinkler)

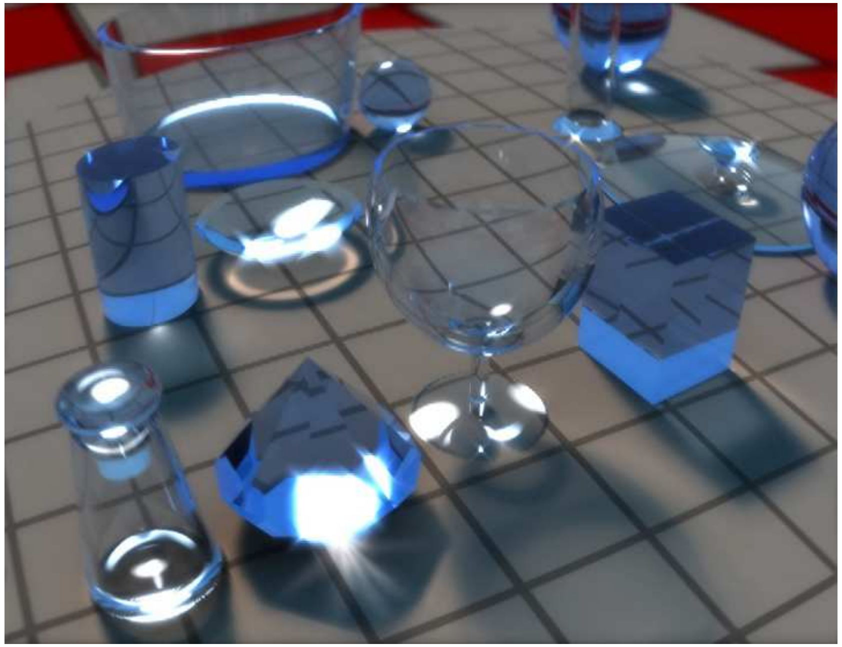
```
PIXELFORMATDESCRIPTOR pfd={0,1,PFD_SUPPORT_OPENGL|PFD_DOUBLEBUFFER, 32, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 32, 0, 0, 0, 0, 0, 0, 0};
DEVMODE dmScreenSettings={ 0,0,0,sizeof(DEVMODE),0,DM_PELSWIDTH|DM_PELSHEIGHT,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1024,768,0,0,0,0,0,0,0,0,0,0};

void WinMainCRTStartup()
{
   ChangeDisplaySettings(&dmScreenSettings,CDS_FULLSCREEN);
   HDC hDC = GetDC(CreateWindow("edit",0,WS_POPUP | WS_VISIBLE | WS_MAXIMIZE, 0,
0, 0, 0, 0, 0, 0, 0));
   SetPixelFormat(hDC, ChoosePixelFormat(hDC, &pfd) , &pfd);
   wglMakeCurrent(hDC, wglCreateContext(hDC));
   ShowCursor(0);
   GLuint p = ((PFNGLCREATEPROGRAMPROC)wglGetProcAddress("glCreateProgram"))();
   GLuint s = ((PFNGLCREATESHADERPROC)(
wglGetProcAddress("glCreateShader")))(GL_VERTEX_SHADER);
   ((PFNGLSHADERSOURCEPROC)wglGetProcAddress("glShaderSource"))(s,1, &vsh,0);
   ((PFNGLCOMPILESHADERPROC)wglGetProcAddress("glCompileShader"))(s);
   ((PFNGLATTACHSHADERPROC)wglGetProcAddress("glAttachShader"))(p,s);
   s = ((PFNGLCREATESHADERPROC)
wglGetProcAddress("glCreateShader"))(GL_FRAGMENT_SHADER);
   ((PFNGLSHADERSOURCEPROC)wglGetProcAddress("glShaderSource"))(s,1, &fsh,0);
   ((PFNGLCOMPILESHADERPROC)wglGetProcAddress("glCompileShader"))(s);
   ((PFNGLATTACHSHADERPROC)wglGetProcAddress("glAttachShader"))(p,s);
   ((PFNGLLINKPROGRAMPROC)wglGetProcAddress("glLinkProgram"))(p);
   ((PFNGLUSEPROGRAMPROC)wglGetProcAddress("glUseProgram"))(p);
   loop:
    int t=GetTickCount();
    glRecti(t,t,-t,-t);
    SwapBuffers(hDC);
    if (GetAsyncKeyState(VK_ESCAPE)) ExitProcess(0);
    goto loop;
}
```

Old-school effects are back

- Pathtracing of simple scenes/primitives

Off the shelf, by Loonies, at Breakpoint 2008 [4k kbytes image]



PhotonRace, by Archee, at Buenzli 2008 [4k kbytes image]

Old-school effects are back

- GPU raytracing beyond spheres and planes (I mean polygons)

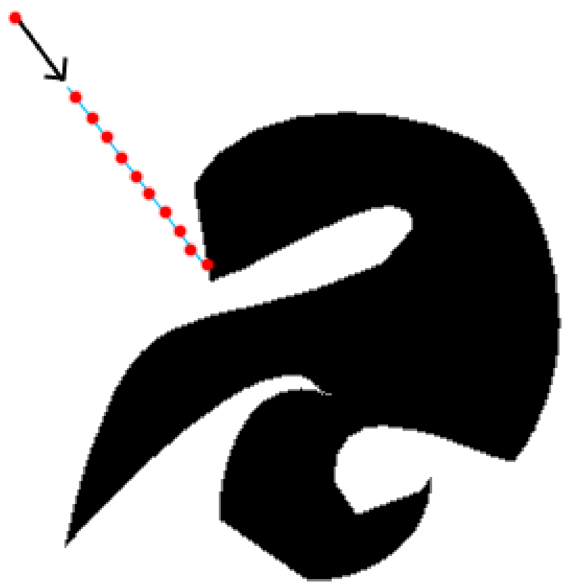
Images reproduced with permision of Vrcontext (www.vrcontext.com)

Old-school effects are back

- GPU raytracing beyond spheres and planes (I mean polygons)
  - A very hot research topic today (because raytracing is the future...)
  - Difficult to beat CPU raytracers
    - kd-tree/bih/bvh traversal is quite incoherent
    - They all need a stack (unavailable today on shaders).
  - For massive models, streaming to video memory is needed. That makes it more complex.
  - In any case, demosceners have not been interested on real raytracing so far; even less in the 4k categories.

Old-school effects are back

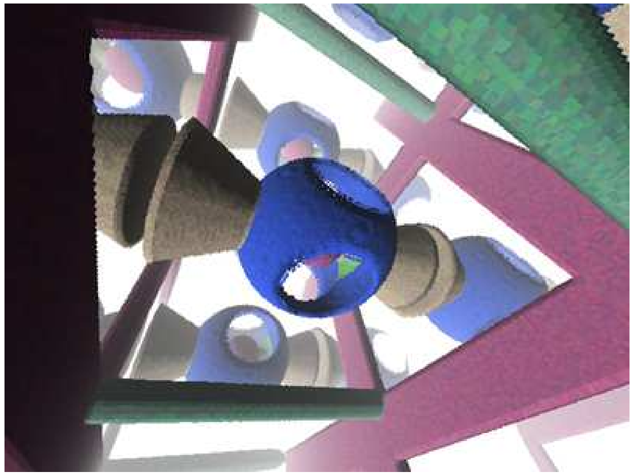
- Raymarching
    - Kind of raytracing for all those objects that don't have an analytic intersection function.



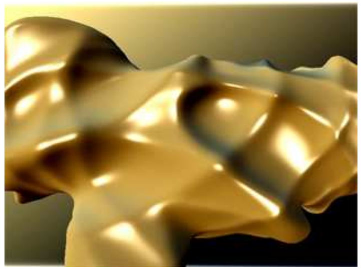
Old-school effects are back

- Raymarching -- what?
  - Heightmaps
  - Volume textures
  - Procedural isosurfacss
  - Analytic surfaces

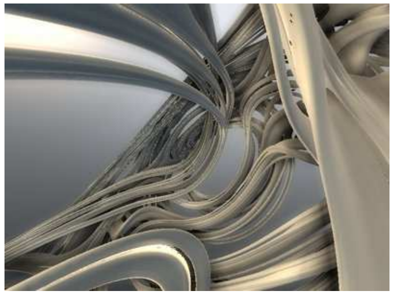
Heightmap raymarching. Hymalaya, by TBC 2008, 1 kbytes demo



3D texture volume raymarching (rgba)



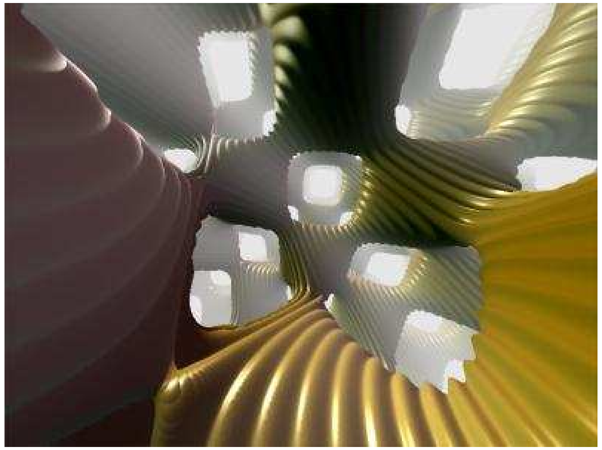
Procedural isosurface



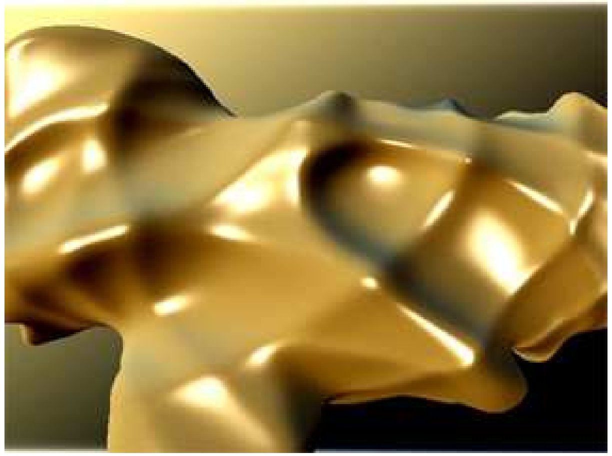
Analytic surface

Old-school effects are back

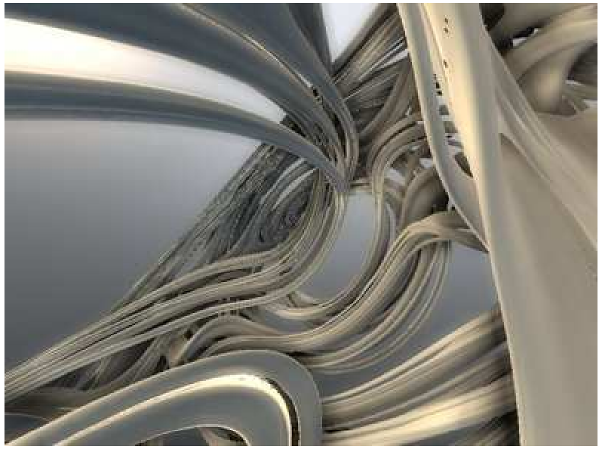
- Raymarching -- how?
  - Constant steps
  - Root finders (bisection, Newton-Raphson...)
  - Distance fields



Failty, by Loonies, 2006, a 4 kbytes demo



Tracie, by TBC, 2007, a 1 kbytes demo



Kindernoiser, by rgba, 2007, a 4 kbytes demo

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- Rendering with distance fields

Rendering with distance fields

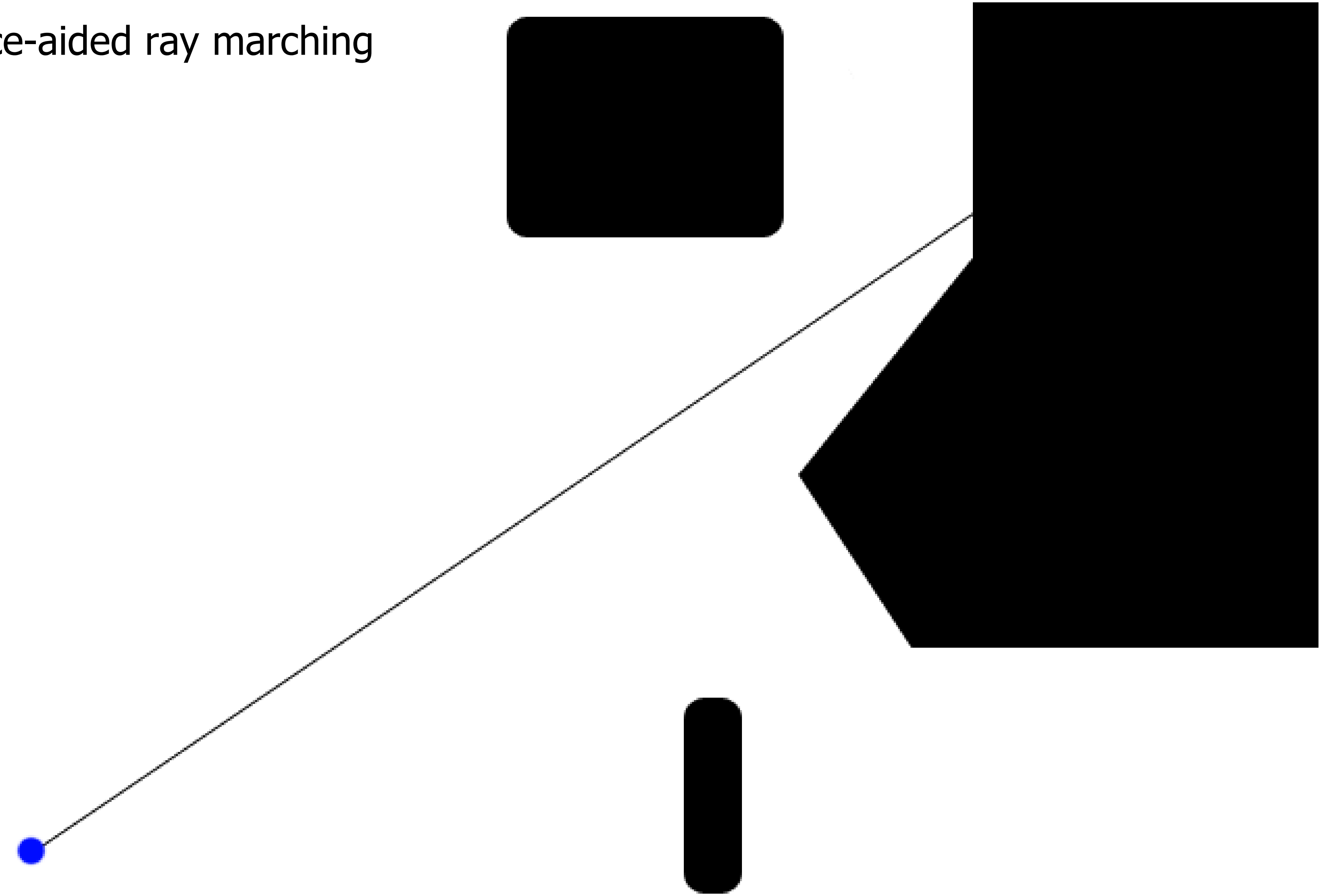
Slisesix, by rgba, at EuskalEncounter 2008 [4k kbytes image]

Rendering with distance fields

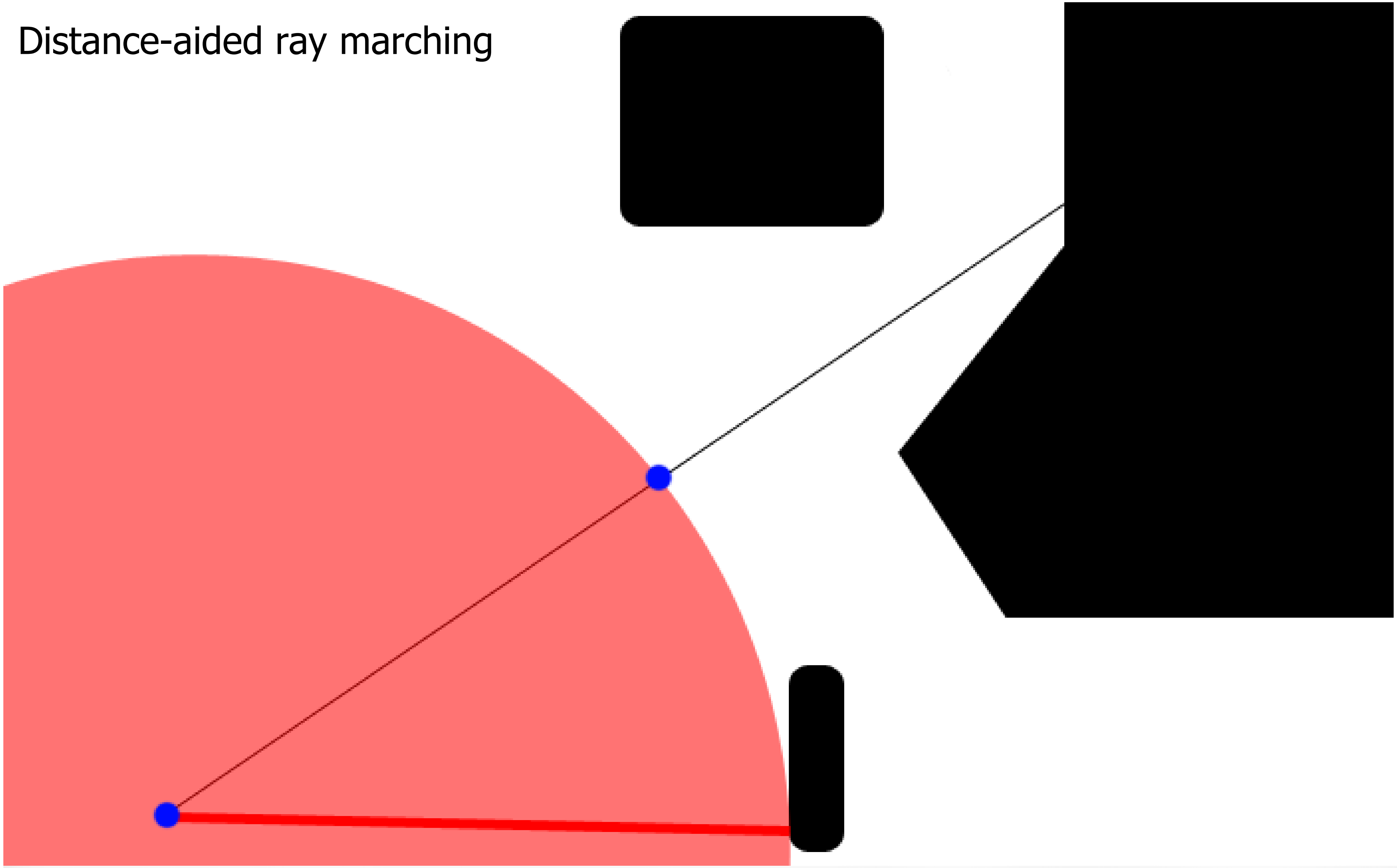
- Similarly previous works
  - “Ray tracing deterministic 3-D fractals” published at Siggraph 1989 by D.J.Sandin and others.
  - “Per-pixel displacement mapping with distance functions”, appeared in GPU Gems 2 (2005) by W.Donnelly.

- The trick is to be able to compute or estimate (a lower bound of) the distance to the closest surface at any point in space.
- This allows for marching in large steps along the ray.

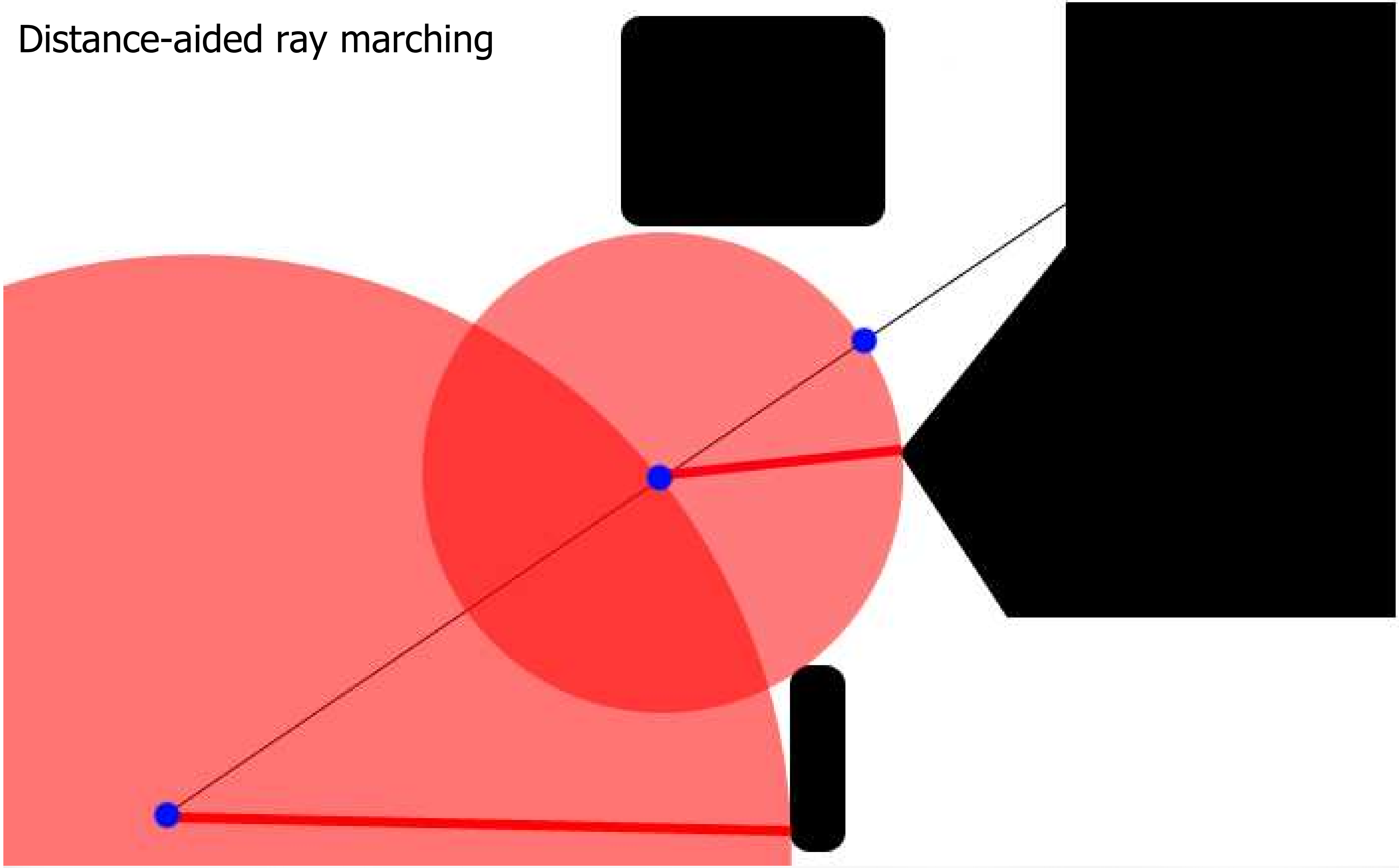
Distance-aided ray marching



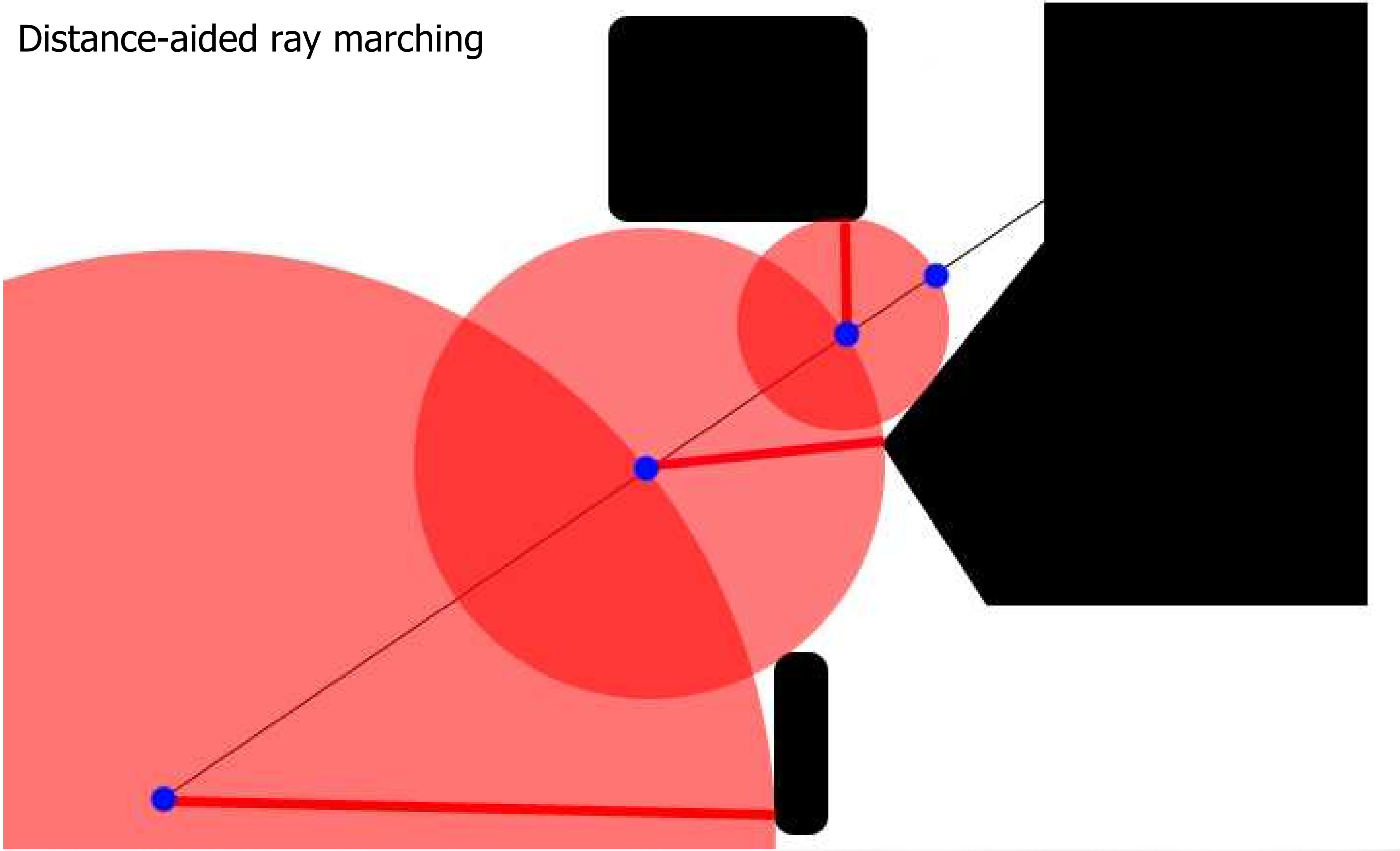
Distance-aided ray marching



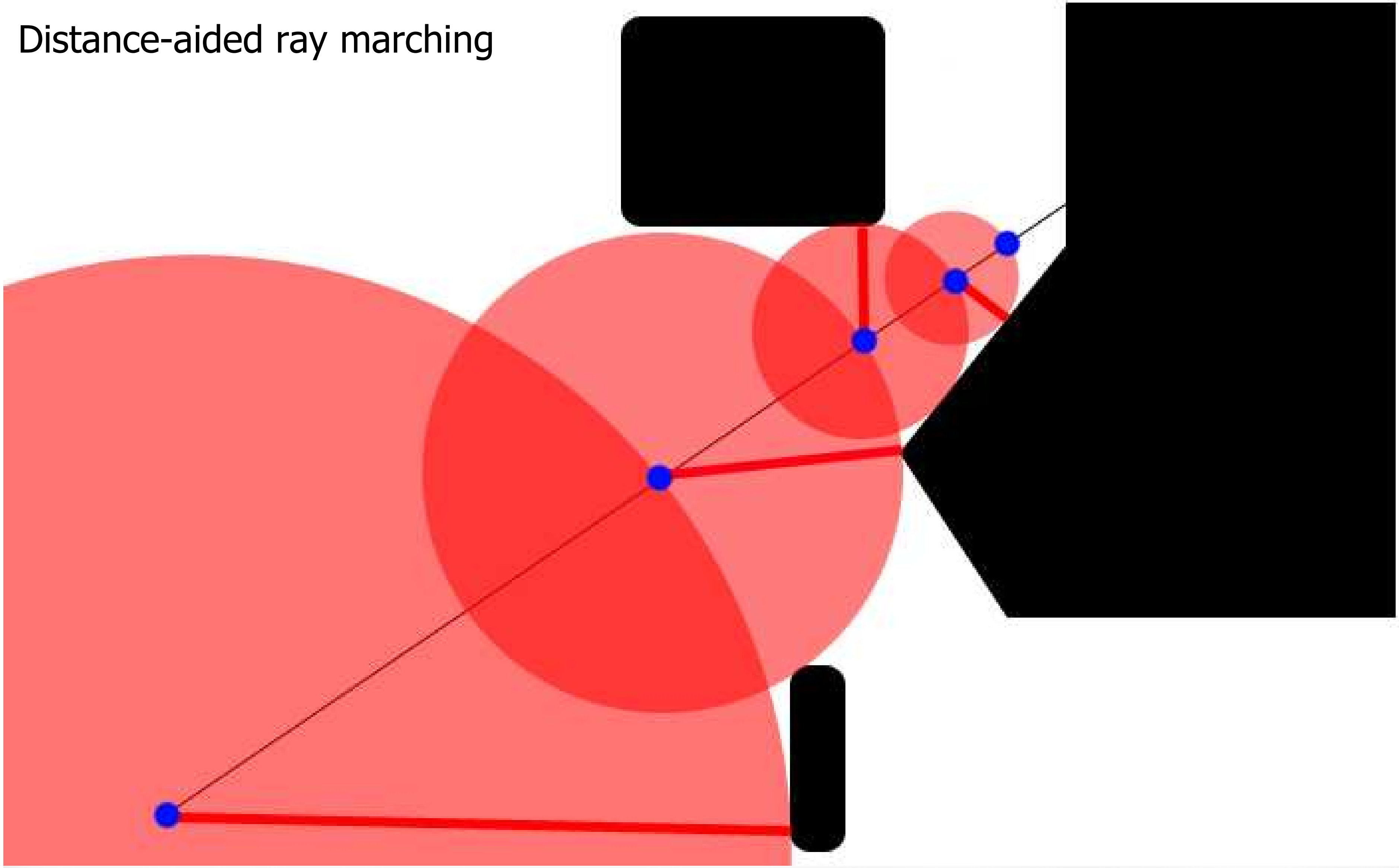
Distance-aided ray marching



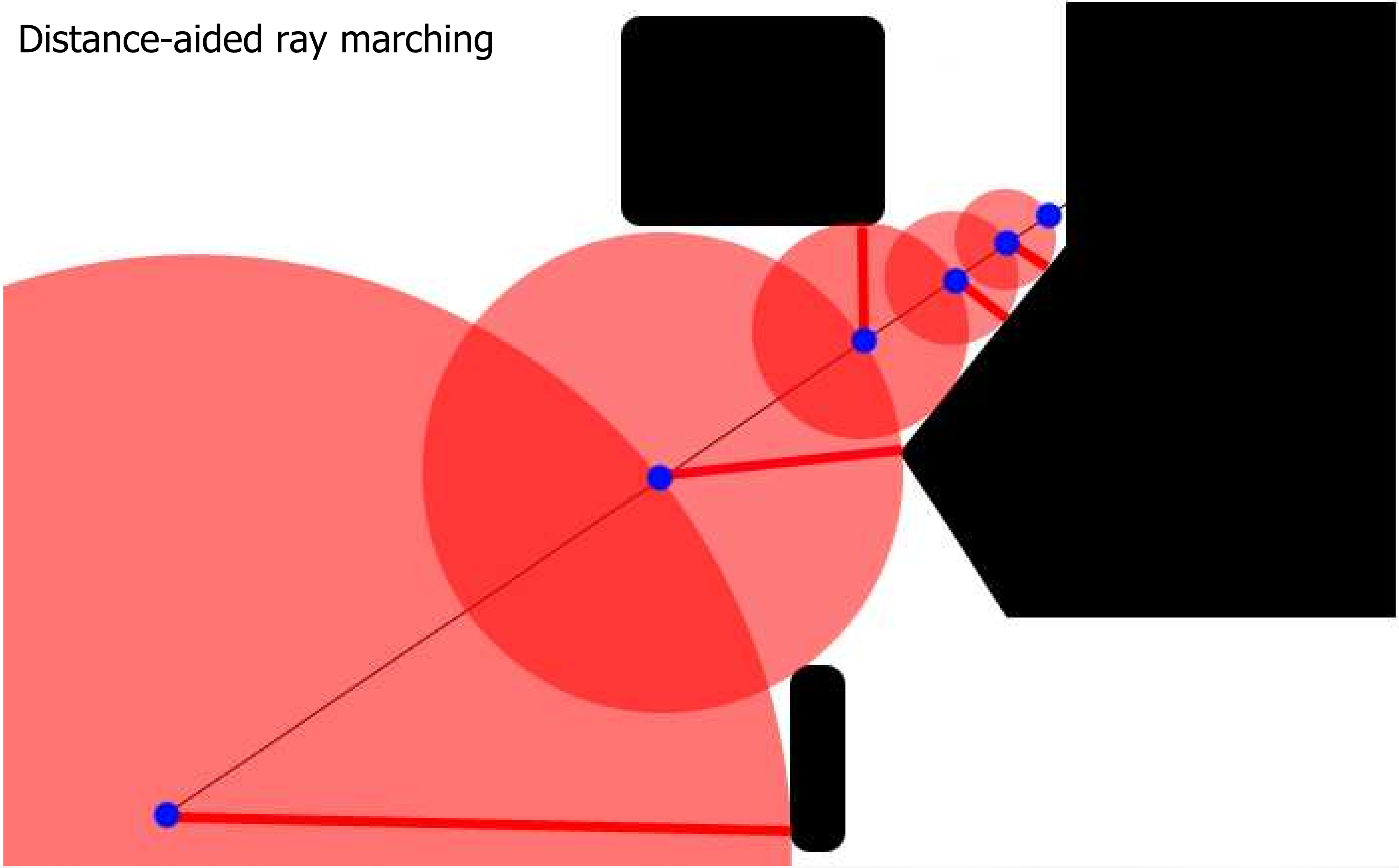
Distance-aided ray marching



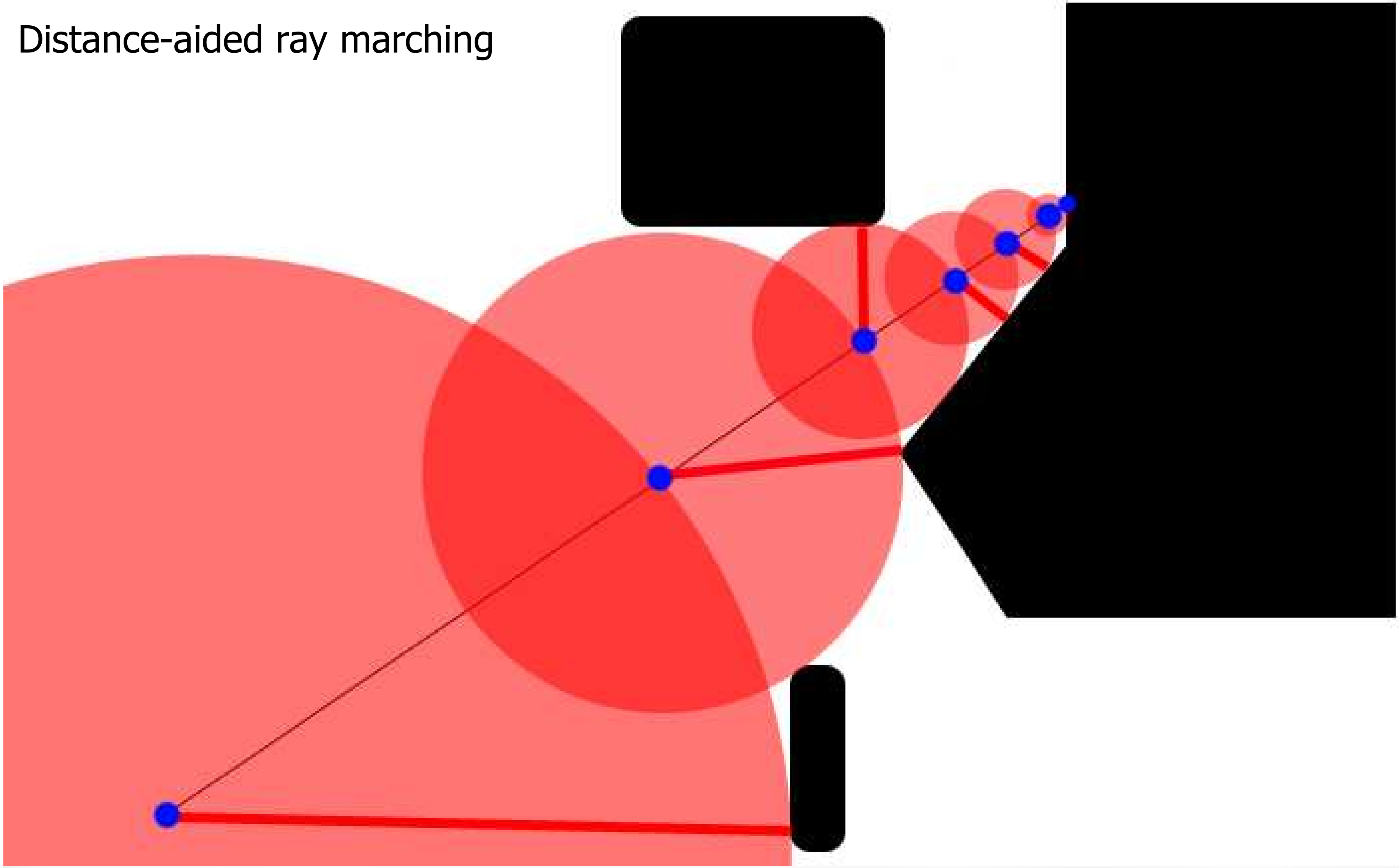
Distance-aided ray marching



Distance-aided ray marching



Distance-aided ray marching



Rendering with distance fields

Pros

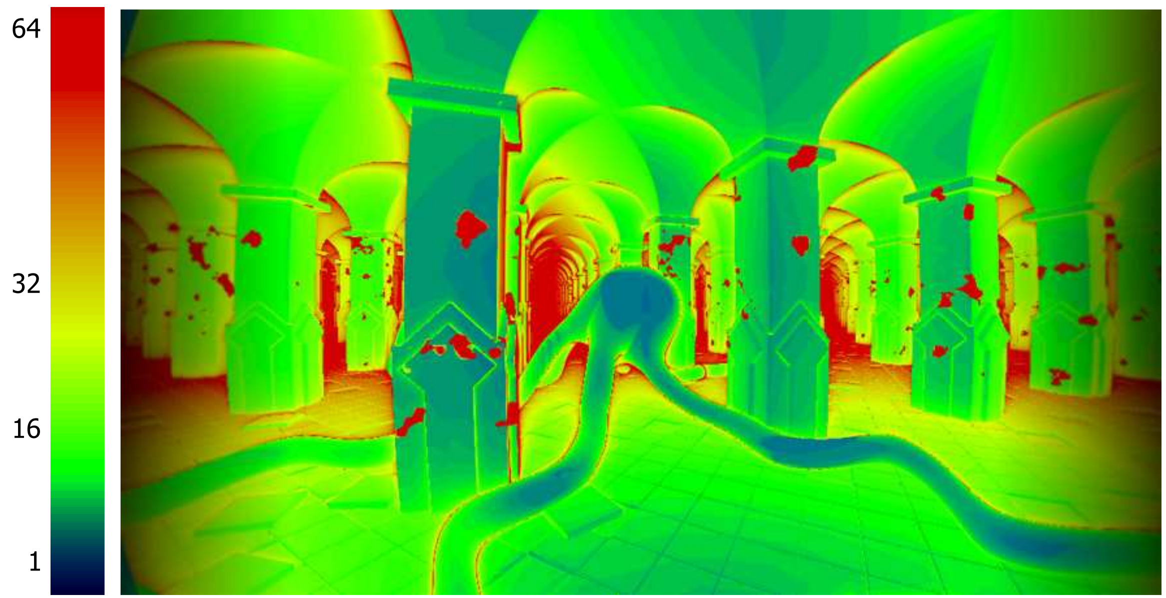
- Much faster than constant-size stepping.
- Much easier to control than root finders (bisection, Newton...)
- Room for optimization, like using bigger steps when we are further from the ray origin
  - Error in world coordinates decreases as $1/d$
  - So stepping proportionally to d results in constant screen space error.

Cons

- Slow on the boundaries of the objects (hopefully not that many pixels).
- Can control it by imposing a minimun step size.

Rendering with distance fields

- Slisesix needs 50 million evaluations of the very expensive distance function for a 1280x720 pixel image.
- 60% of the evaluations are for primary rays (av. 17 steps per ray).
- 40% of the evaluations are for lighting and shading.
- Note the very expensive marching on the object edges.



Number of raymarching steps for primary rays encoded as colors

Rendering with distance fields

- We need a distance field:
  - Analytic computation ("Ray tracing deterministic 3-D fractals")
  - Precomputed (static scene) LUT
    - 3D texture ("Per pixel displacement mapping with distance functions")
    - Octree / KdTree
  - What if we do it 100% procedurally? ("Slisesix")

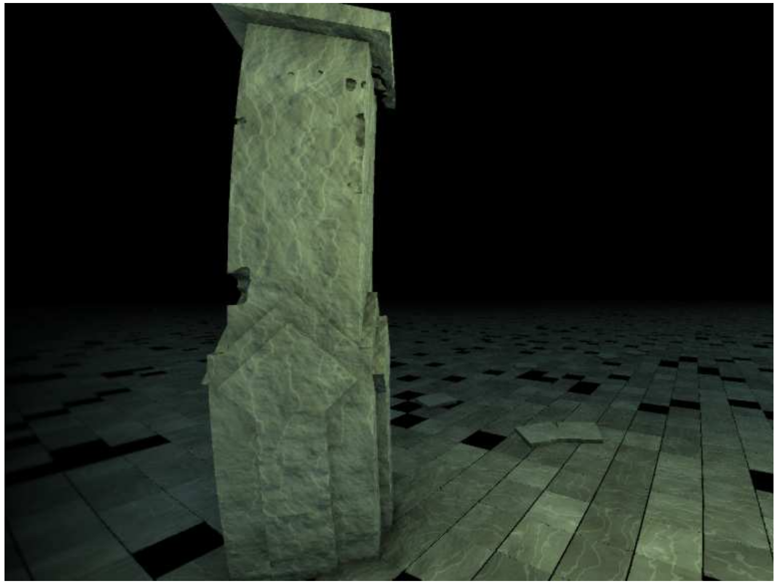
Rendering with distance fields

- Procedural distance fields
  - Don’t define the surface first and then compute the distance field, but directly code a distance field and a surface will emerge.
  - Tweak the distance field directly until you get what you want/can.
  - Helpful techniques that can be used:
    - Arbitrary combination and instantiation
    - Inifinite repetition
    - Deforming space: twisting, bending, deforming
    - Cheap detail surfaces
    - Blend shapes

Rendering with distance fields :: Combination

- Combination of (instanced) distance fields can be done by taking the min of the distance fields involved.
- Instance transformation can be done by inverse transforming the domain (the input to the distance function).

```
float combinedDistanceField( vec3 p )
{
    float dist1 = distanceField_A( M1inv*p );
    float dist2 = distanceField_A( M2inv*p );
    float dist3 = distanceField_B( M3inv*p );
    return min( dist1, min( dist2, dist3 ) );
}
```



Rendering with distance fields :: Domain repetition

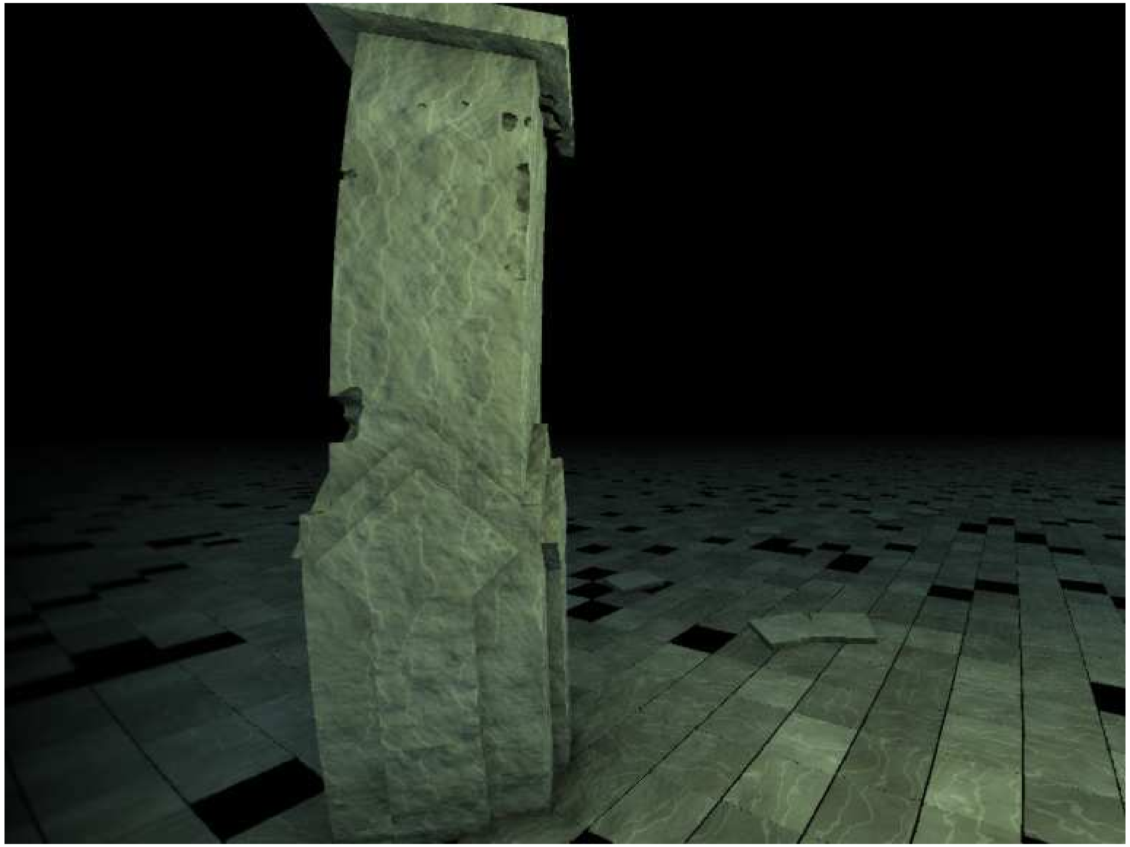
- dist = fourMagicColumns(p.x, p.y, p.z);

Rendering with distance fields :: Domain repetition

- dist = fourMagicColumns(mod(p.x,1), p.y, mod(p.z,1));

Rendering with distance fields :: Domain distortion

```
float dist = distanceToColumn(p);
```

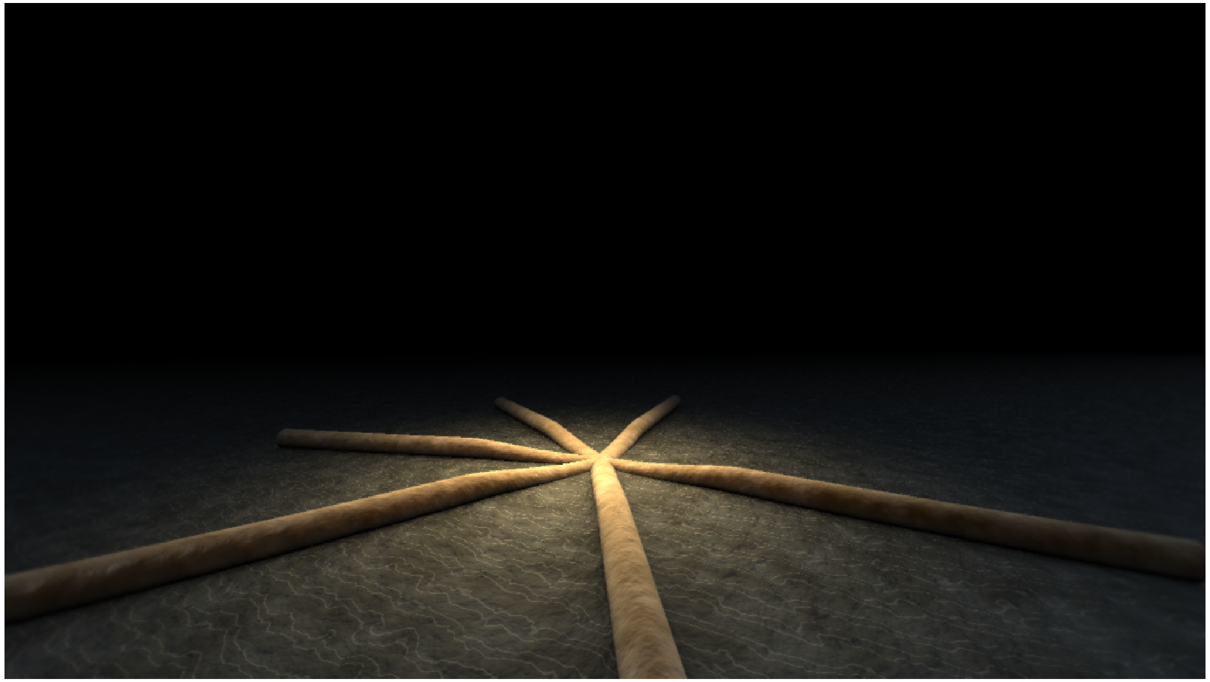


Rendering with distance fields :: Domain distortion

```
float twistedColumn( vec3 p )
{
    vec3 q = rotateY(p, p.y*1.7);
    return distanceToColumn(q);
}
```

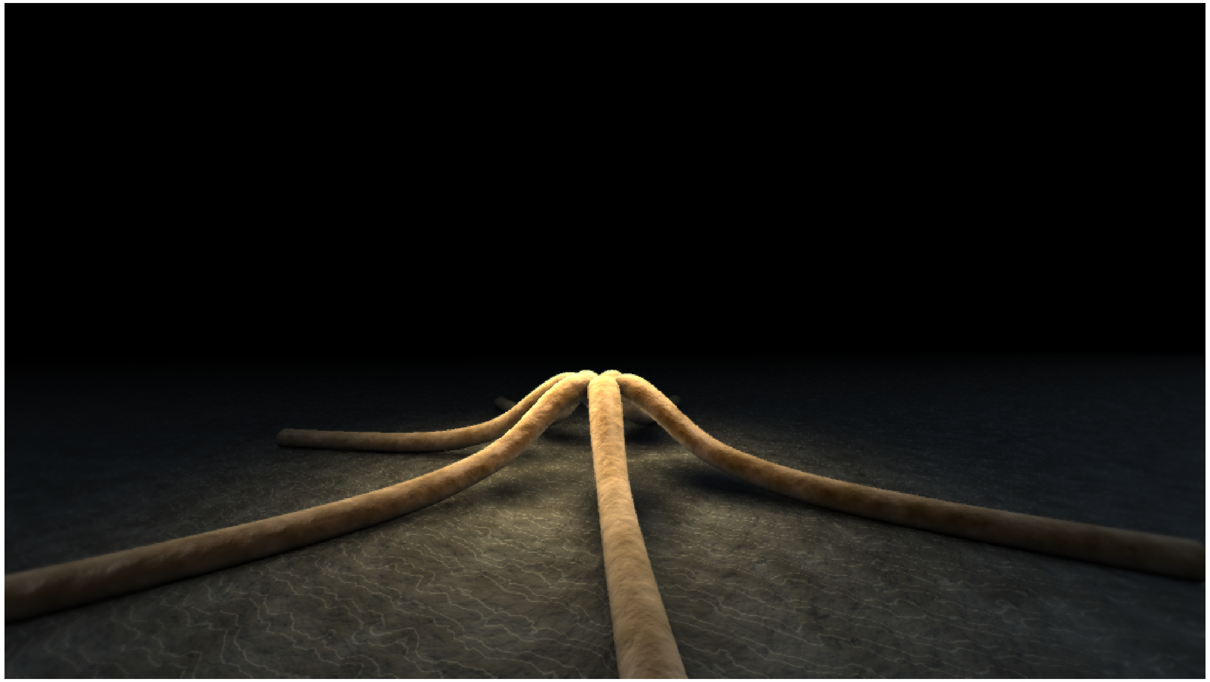
Rendering with distance fields :: Domain distortion

```
float rr = dot(p.xy,p.xy);
for( int i=0; i<6; i++ )
{
    vec3 q = rotateY( p, TWOPI*i/6.0 );
    distance = min( distance, distanceToTheXAxis(q) );
}
```



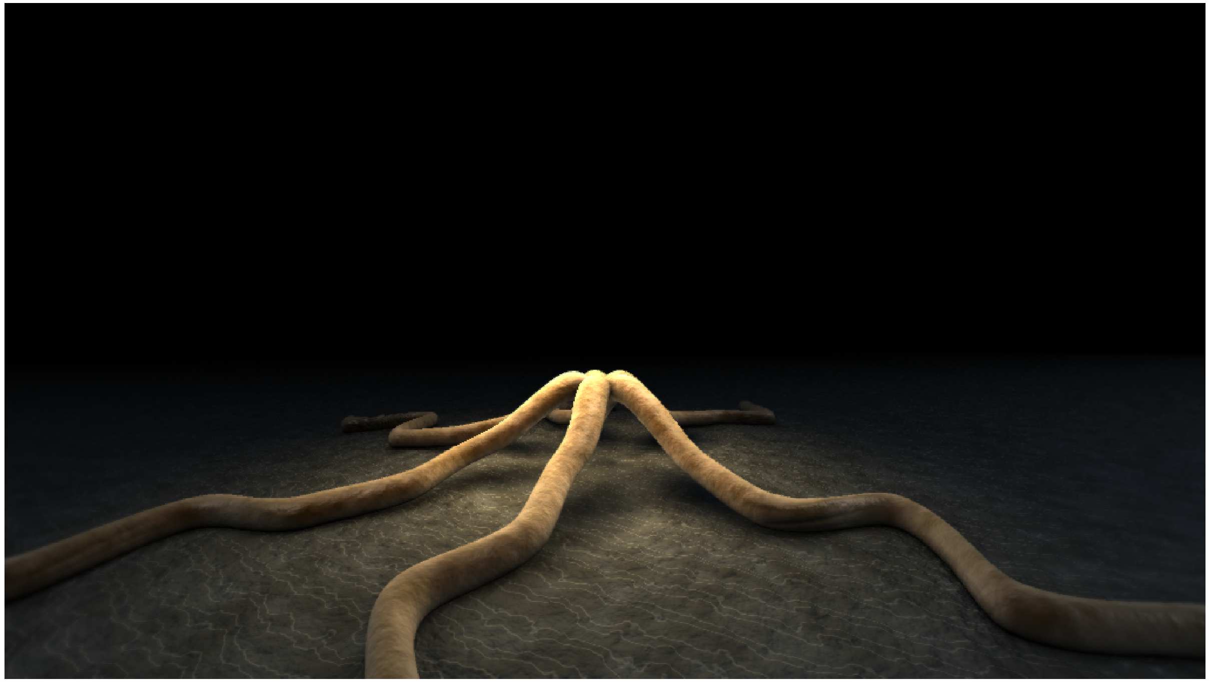
Rendering with distance fields :: Domain distortion

```
float rr = dot(p.xy,p.xy);
for( int i=0; i<6; i++ )
{
    vec3 q = rotateY( p, TWOPI*i/6.0 );
    q.y += 0.6*rr*exp2(-10.0*rr);
    distance = min( distance, distanceToTheXAxis(q) );
}
```

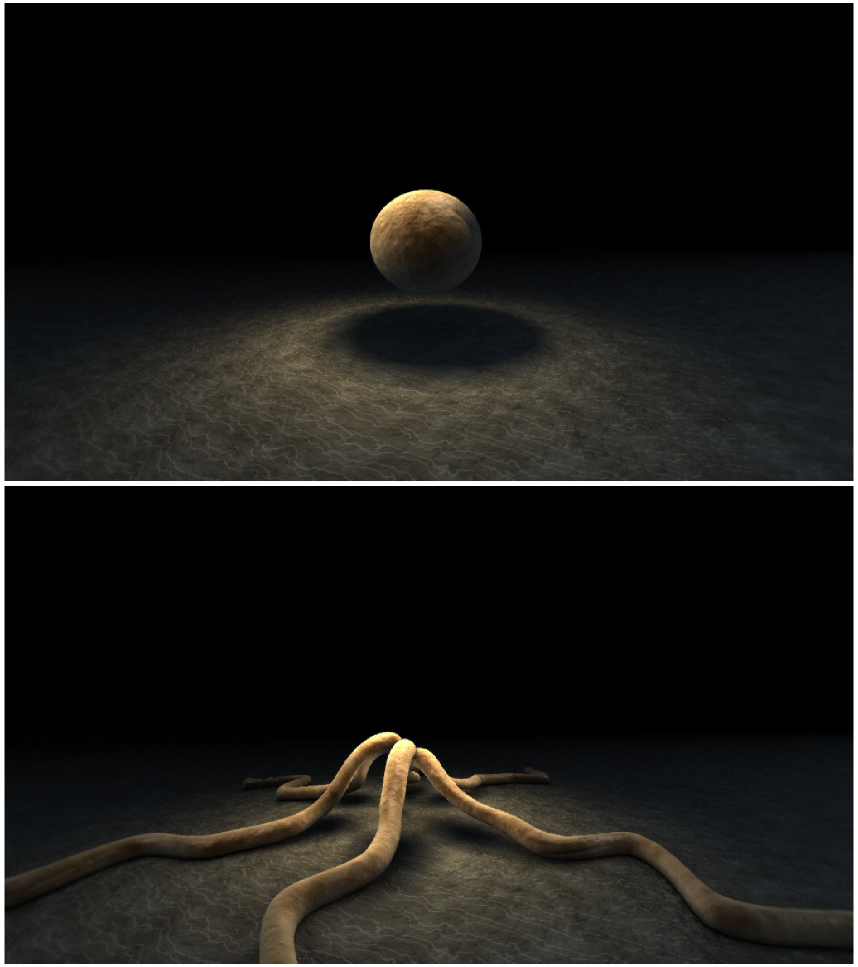


Rendering with distance fields :: Domain distortion

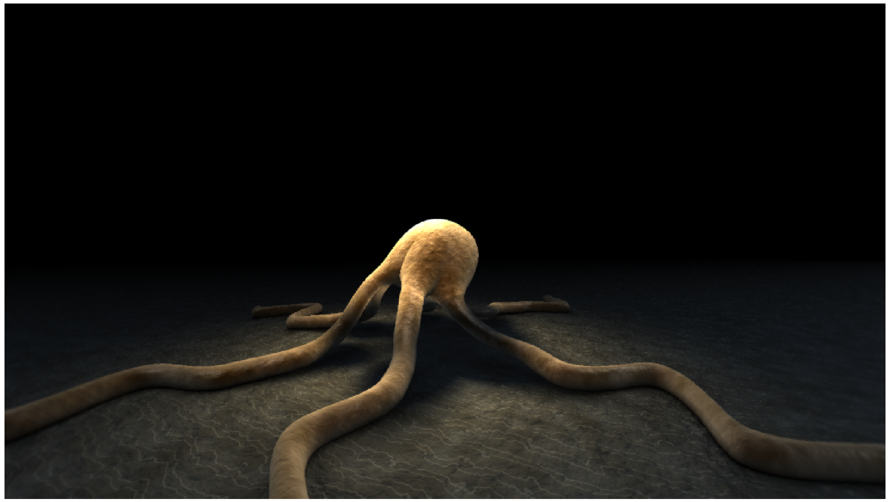
```
float rr = dot(p.xy,p.xy);
for( int i=0; i<6; i++ )
{
    vec3 q = rotateY( p, TWOPI*i/6.0 + 0.4*rr*noise2f(vec3(4*rr,6.3*i)) );
    q.y += 0.6*rr*exp2(-10.0*rr);
    distance = min( distance, distanceToTheXAxis(q) );
}
```



Rendering with distance fields :: Blending fields



```
float distanceToMonster( vec3 p )
{
  float dist1 = distanceToBall(p);
  float dist2 = distanceToTentacles(p);
  float bfact = smoothstep( length(p), 0, 1 );
  return mix( dist1, dist2, bfact );
}
```



Rendering with distance fields :: Adding details

```
dist = distanceToColmuns(p);
```

Rendering with distance fields :: Adding details

```
dist = distanceToColmuns(p) + 0.000001*clamp(fbm(p), 0, 1);
```

Rendering with distance fields :: Lighting

- Lighting
  - Normals
  - Bump mapping
  - Soft shadows
  - Ambient Occlusion

Rendering with distance fields :: Lighting

- Normals computed by central differences on the distance field at the shading point (gradient approximation).
- Bump map computed by adding the gradient of a fractal sum of Perlin noise functions to the surface normal.
  - n = normalize(grad(distance, p)) + bump*grad(fbm, p)));
  - *bump* is small and depend on the material.
  - grad(func, p) = normalize(

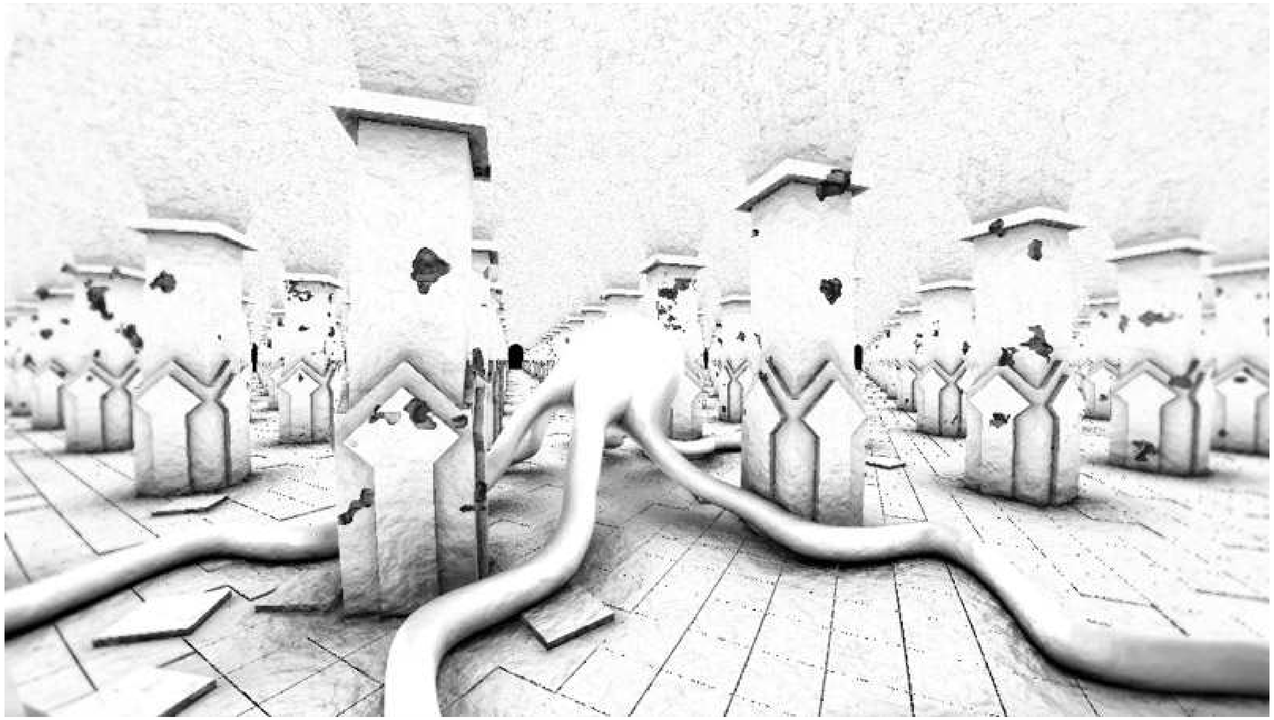
    func(p+{eps,0,0}) - func(p-{eps,0,0}),

    func(p+{0,eps,0}) - func(p-{0,eps,0}),

    func(p+{0,0,eps}) - func(p-{0,0,eps}));

Rendering with distance fields :: Ambient Occlusion

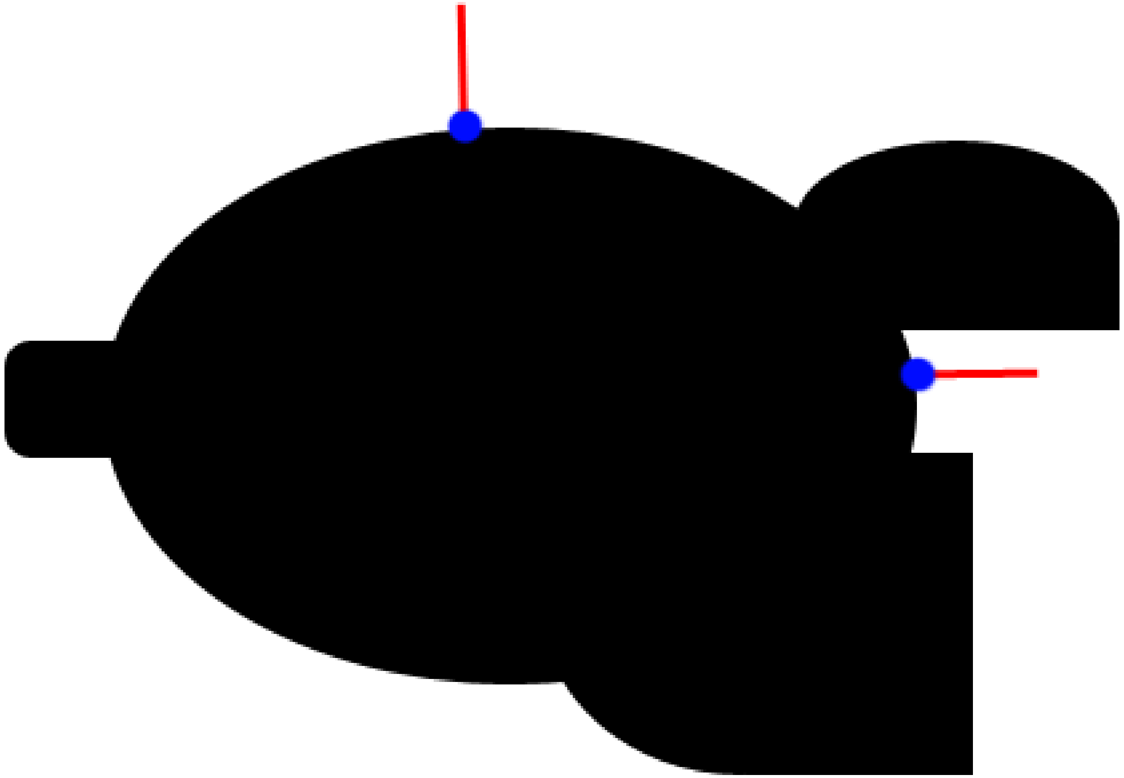
- Fake and fast Ambient Occlusion.
- VERY CHEAP, even cheaper than primary rays! Only 5 distance evaluations instead of casting thousand of rays/evaluations.



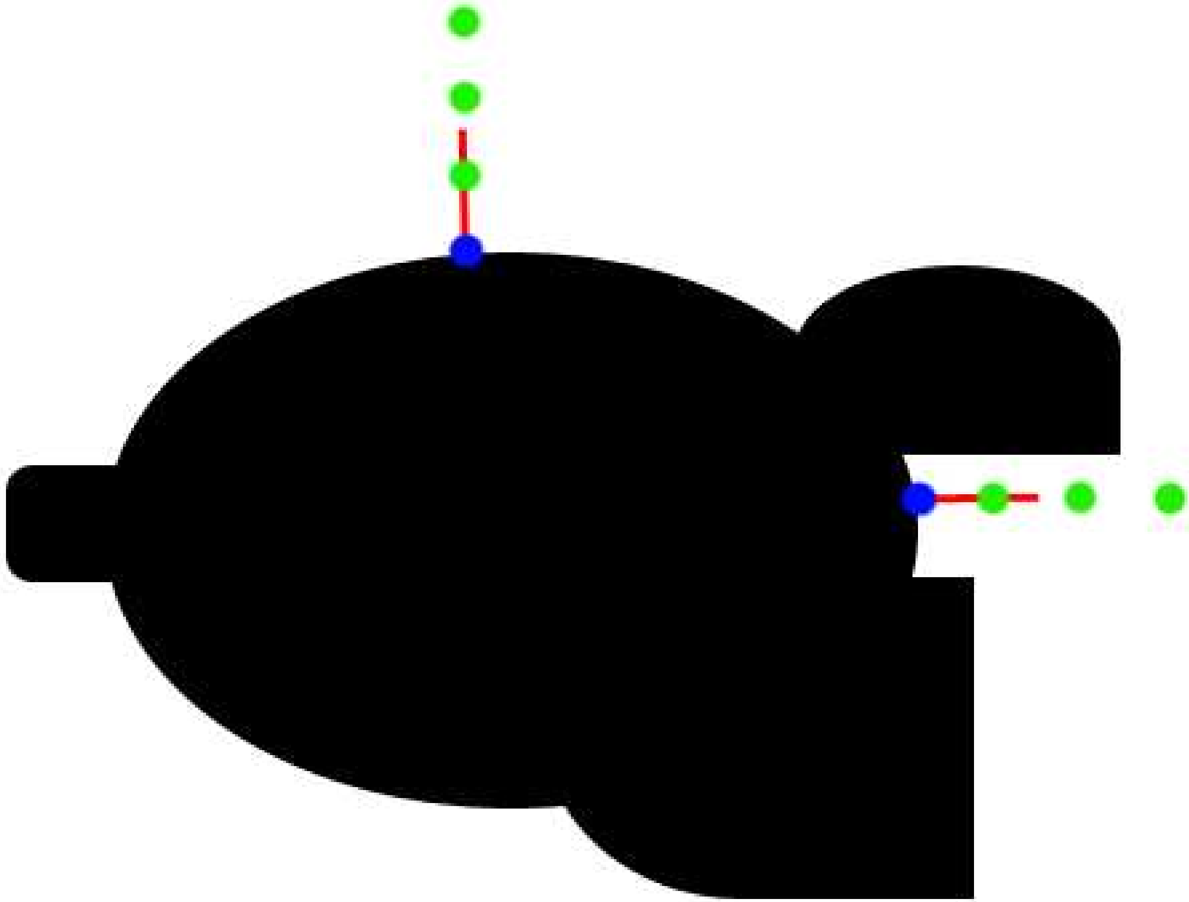
Rendering with distance fields :: Ambient Occlusion

- In a regular raytracer, primary rays/AO cost is 1:2000. Here, it's 3:1 (that's almost four orders of magnitude speedup!).
- It's NOT the screen space trick (SSAO), but 3D.
- The basic technique was invented by Alex Evans, aka Statix ("Fast Approximation for Global Illumnation on Dynamic Scenes", 2006). Greets to him!
- The idea: let *p* be the point to shade. Sample the distance field at a few (5) points around *p* and compare the result to the actual distance to *p*. That gives surface proximity information that can easily be interpreted as an (ambient) occlusion factor.

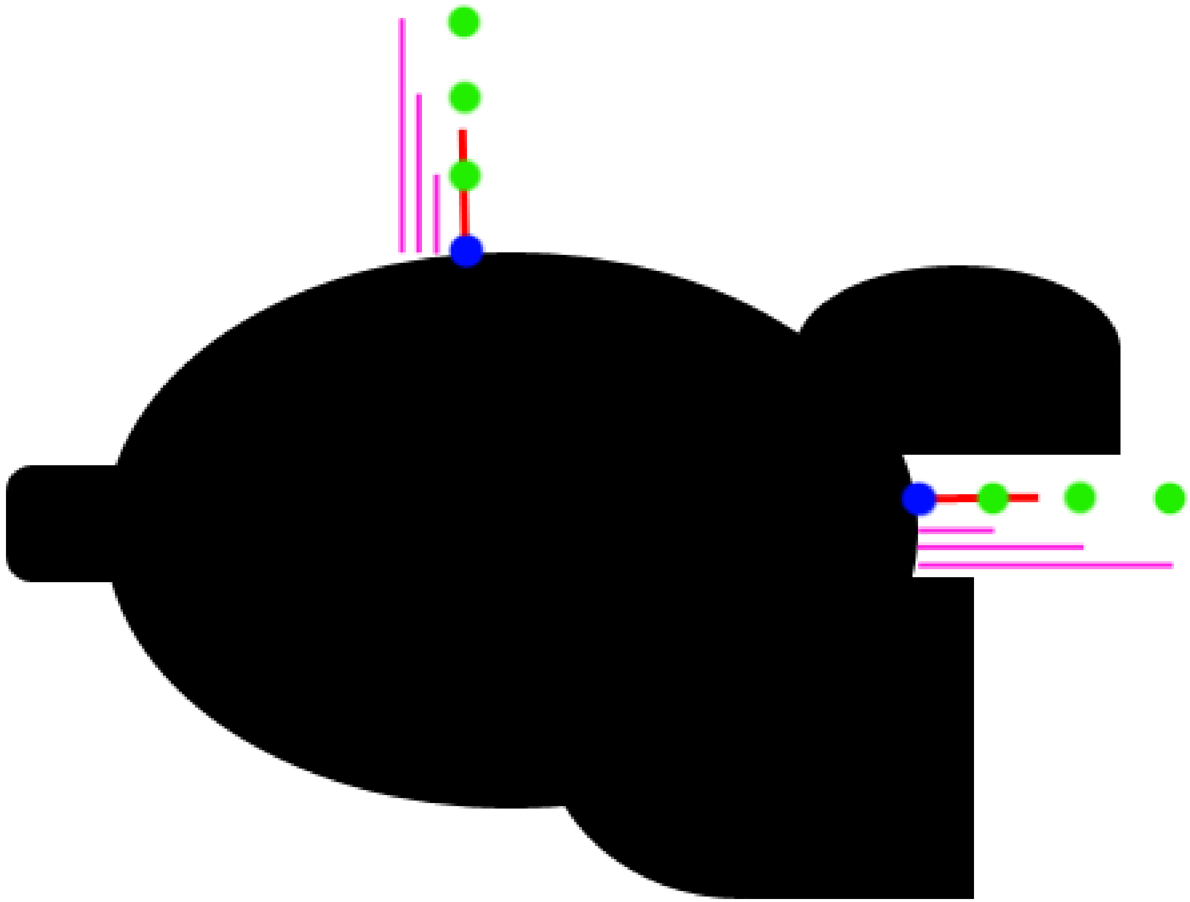
Rendering with distance fields :: Ambient Occlusion



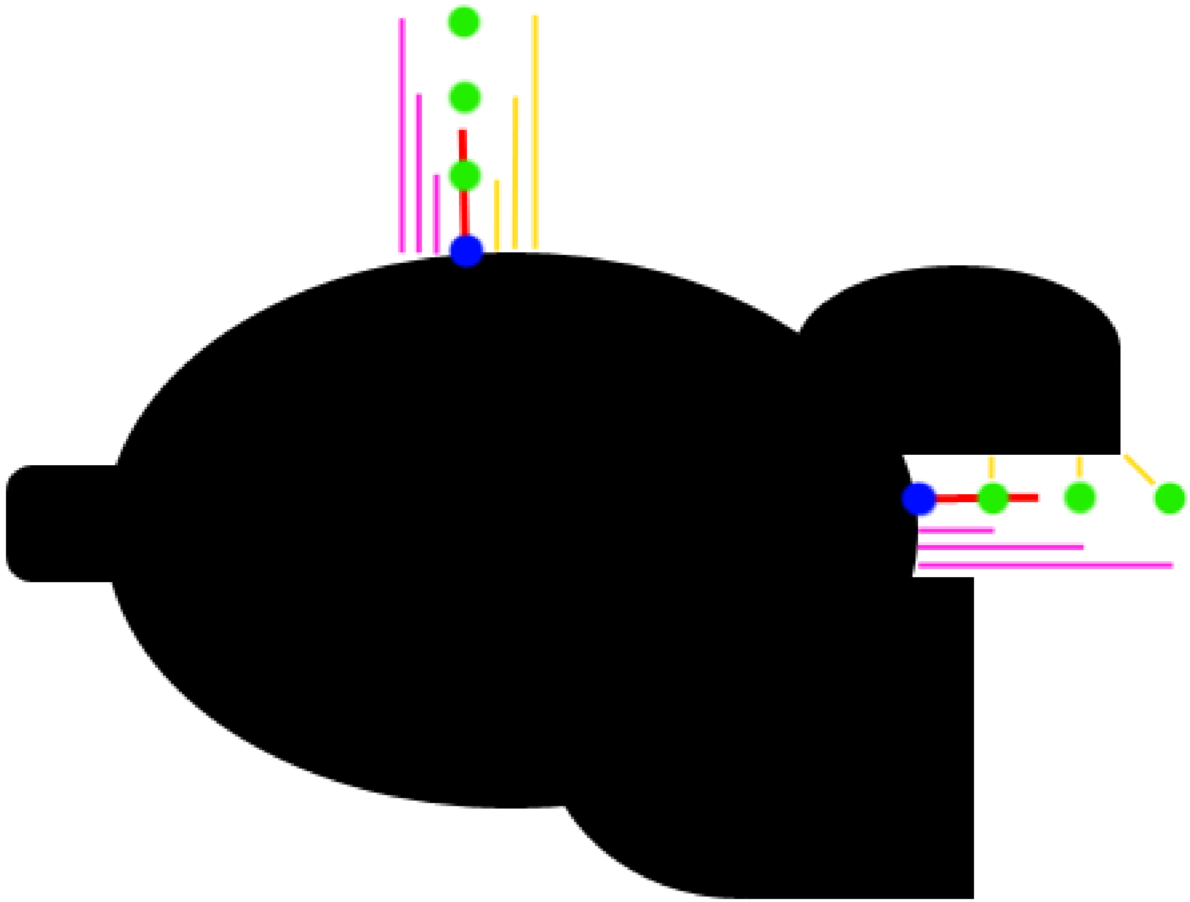
Rendering with distance fields :: Ambient Occlusion



Rendering with distance fields :: Ambient Occlusion



Rendering with distance fields :: Ambient Occlusion

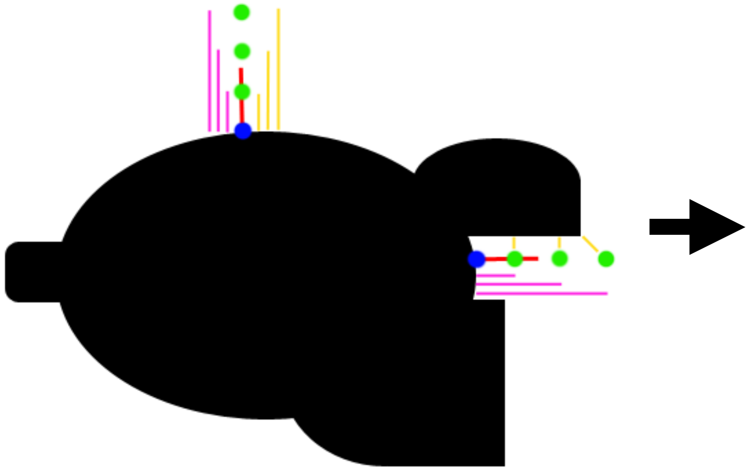


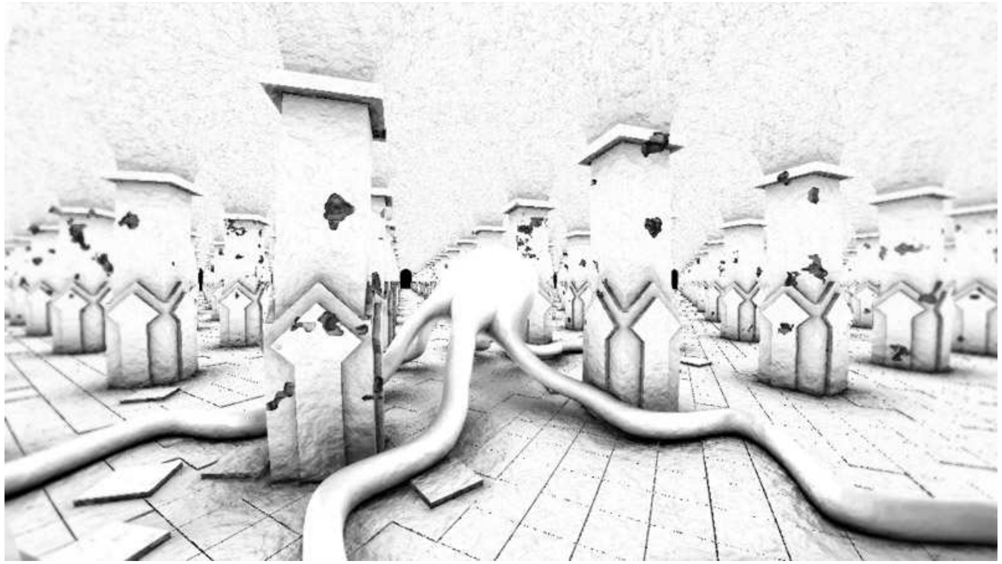
Rendering with distance fields :: Ambient Occlusion

$$ao = 1 - k \cdot \sum_{i=1}^{5} \frac{1}{2^i} \left(pink_i - yellow_i \right)$$

$$ao = 1 - k \cdot \sum_{i=1}^{5} \frac{1}{2^i} \left(i \cdot \Delta - distfield(p + n \cdot i \cdot \Delta) \right)$$

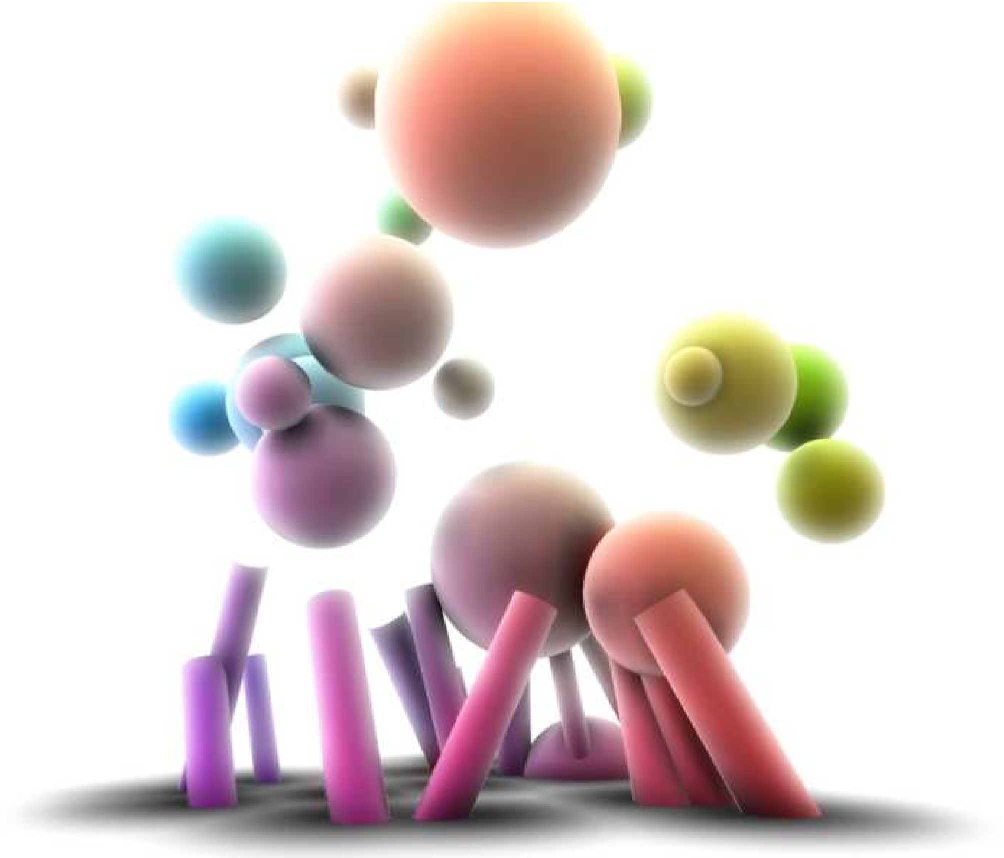
- The exponential decay is there so further away surfaces occlude less than near by ones.





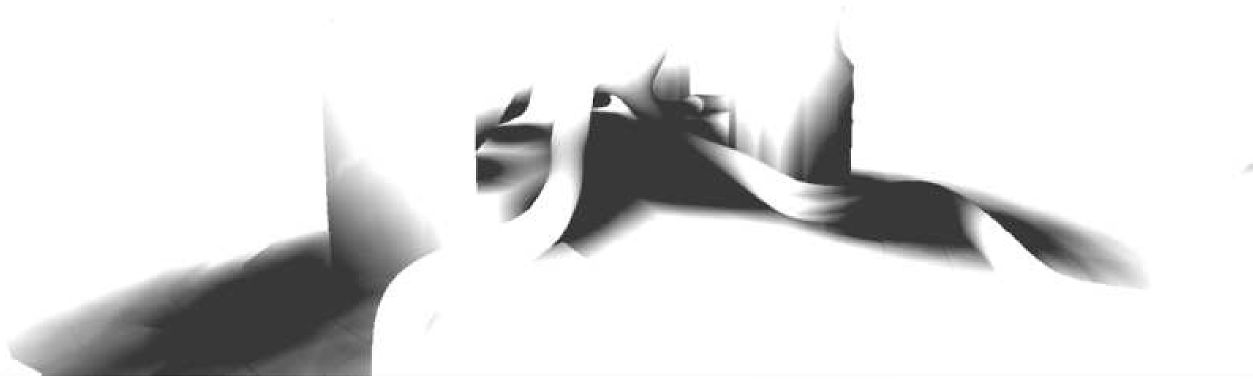
Rendering with distance fields :: Ambient Occlusion

- Works in realtime too, provided you can compute distances to surfaces.



Rendering with distance fields :: Soft Shadows

- Fake and fast soft shadows.
- Only 6 distance evaluations used instead of casting hundrends of rays.
- Pure geometry-based, not bluring.
- Recipe: take *n* points on the line from the surface to the light and evaluate the distance to the closest geometry. Find a magic formula to blend the *n* distances to obtain a shadow factor.



Rendering with distance fields

• On a GeForce 8800 GTX, it renders around 20 times faster than on a dual core CPU. It will very soon be realtime.

Rendering with distance fields

- Related info:
  - “Making graphics in 4 kilobytes”: http://www.rgba.org/iq/divulgation/inspire2008/inspire2008.htm
  - “Advanced perlin noise”: http://rgba.scenesp.org/iq/computer/articles/morenoise/morenoise.htm