Real-time Graphics

8. Geometry Optimalization

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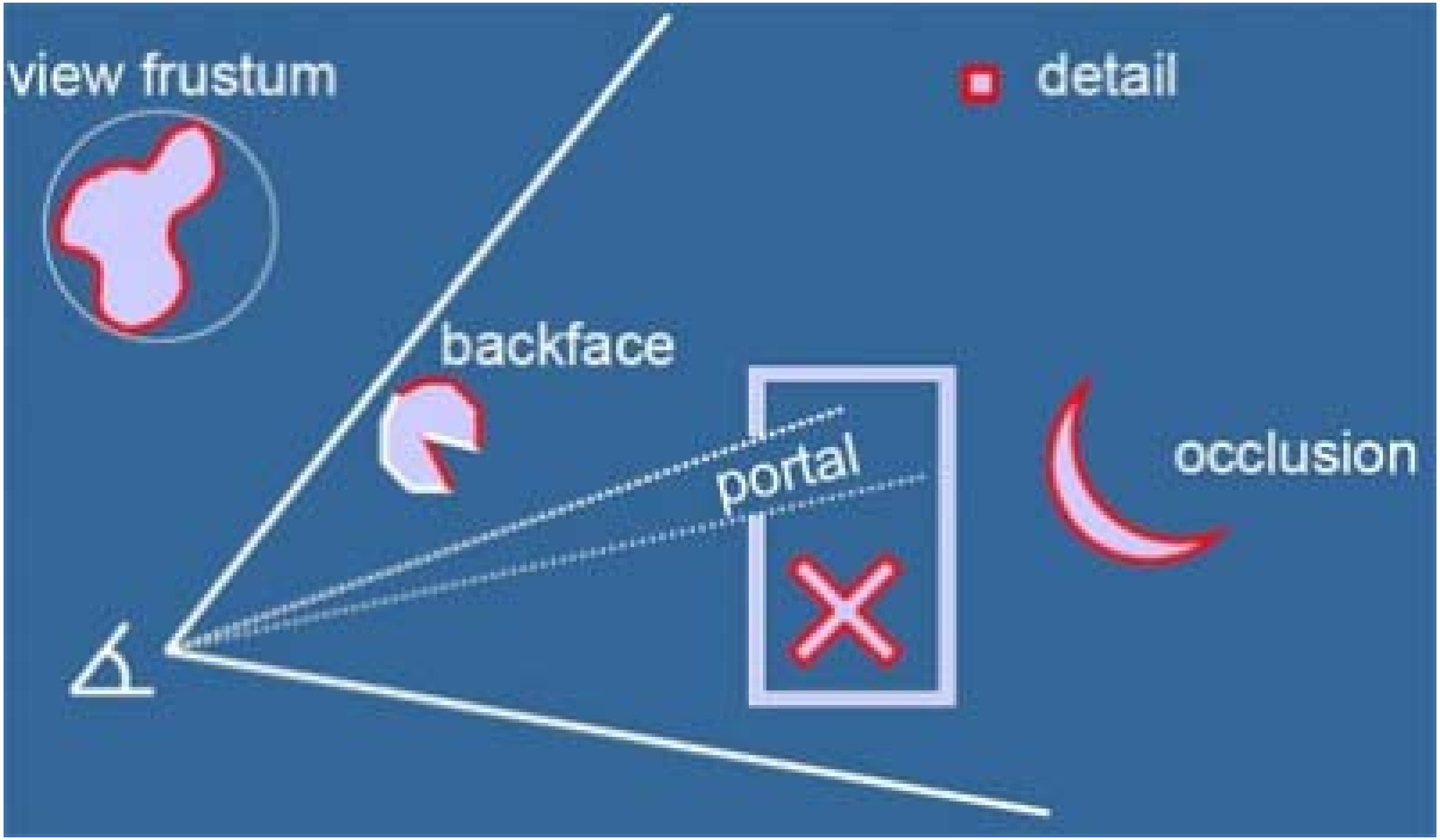
Geometry

- PS3 – 275 million triangles per second = 4,6 million triangles per frame (60 fps)
- XBOX – 500 million triangles per second
- Still needed optimalization to reduce number of triangles or how array of triangles is sent for GPU processing
- Preprocessing stage
- On fly CPU, GPU processing

Reducing geometry

- Reduce number of triangles used for frame rendering
- Eliminate triangles (buffers) that are not visible
- Eliminate or simplify triangles with only few pixels on screen
- Use GPU to create triangles

Culling



[www.gamerendering.com]

Back-face culling

- Front faces given by order of vertices based on winding in window coordinates
  - *void glFrontFace(GLenum mode)*
  - *mode* - GL_CCW, GL_CW
- Remove faces with given facing from rendering pipeline, usually we want remove back faces
  - *void glCullFace(GLenum mode)*
  - *mode* - GL_FRONT, GL_BACK, GL_FRONT_AND_BACK
- Needed model with proper vertices ordering

Frustum culling

- Remove triangles from rendering that are not inside viewing frustum
- Triangle-frustum intersection
- Using simple bounding volumes for objects
  - Sphere
  - Axis aligned bounding box, Oriented bounding box
  - kDOP
- Using hierarchy of bounding volumes
- Volume-frustum intersection

Occlusion culling

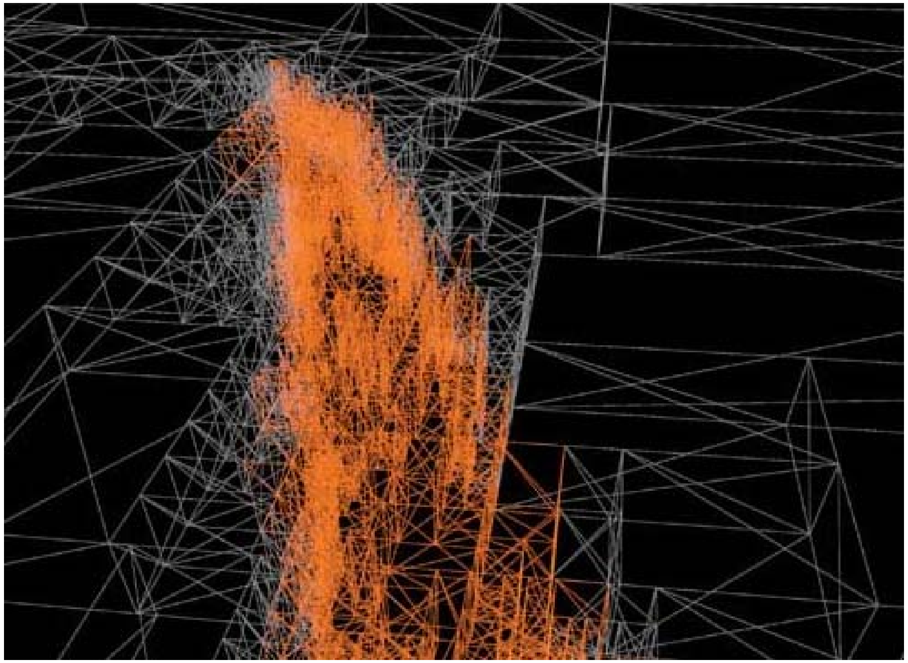
- Remove triangles from rendering that are not visible from current viewpoint
- Static scene – preprocessing, visibility between cells (grid), (Potentially visible set)
- Portal culling – visibility between rooms (cells) connected with doors (portals)
- Dynamic scene – determine if parts of scene are visible or occluded

Occlusion culling

- GPU support – *GL_ARB_occlusion_query*, *GL_ARB_occlusion_query2*
- Computes number of visible pixels for rendered named object (or just boolean value)
- Problems: CPU stalls (waiting for query results), many queries
- Using bounding volume hierarchies
  - Issue occlusion query for the node.
  - Stop and wait for the result of the query.
  - If the node is visible:
    - If it is an interior node:
      - Sort the children in front-to-back order.
      - Call the algorithm recursively for all children.
    - If it is a leaf node, render the objects contained in the node.

Occlusion culling

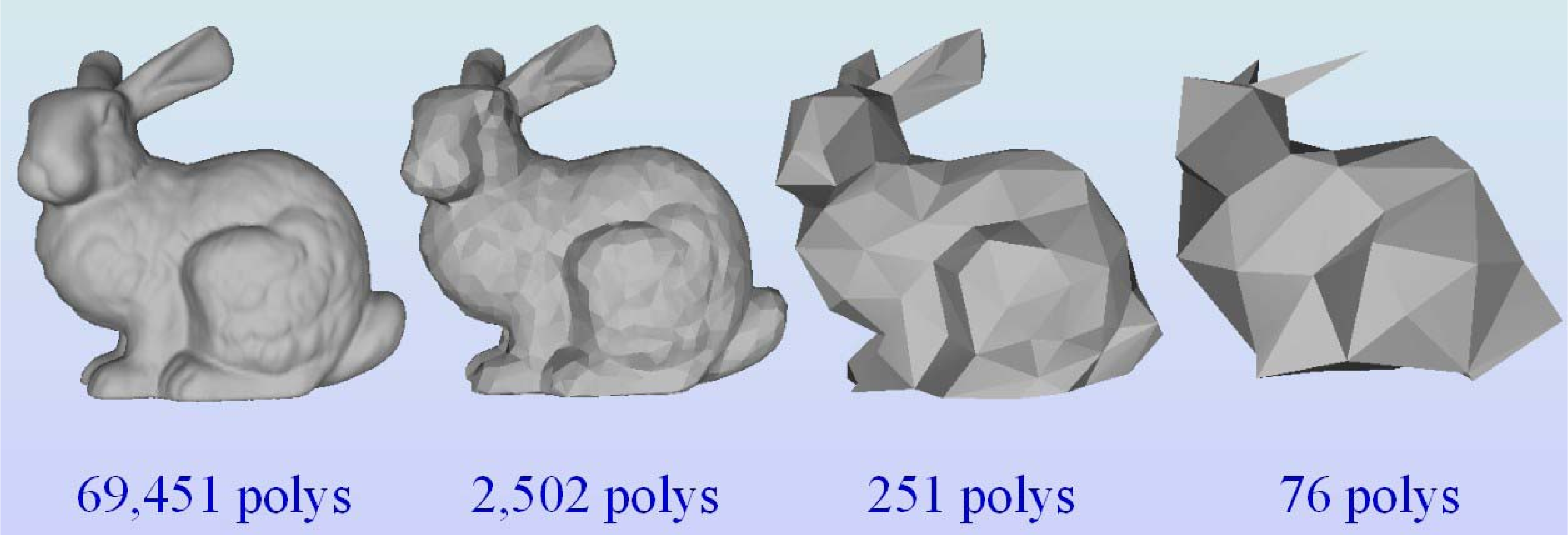
http://developer.nvidia.com/node/23



[Michael Wimmer, Jirí Bittner]

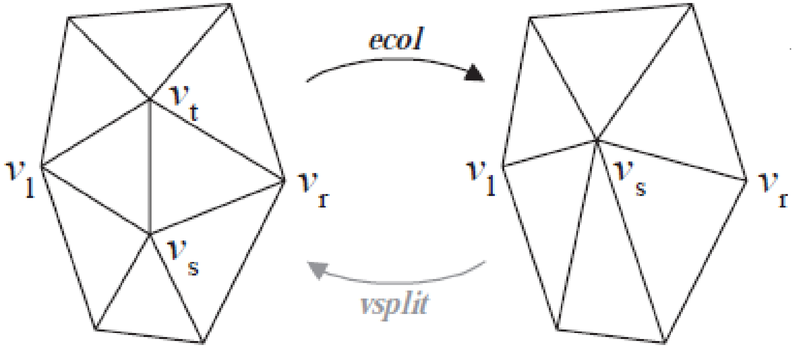
Levels of Detail

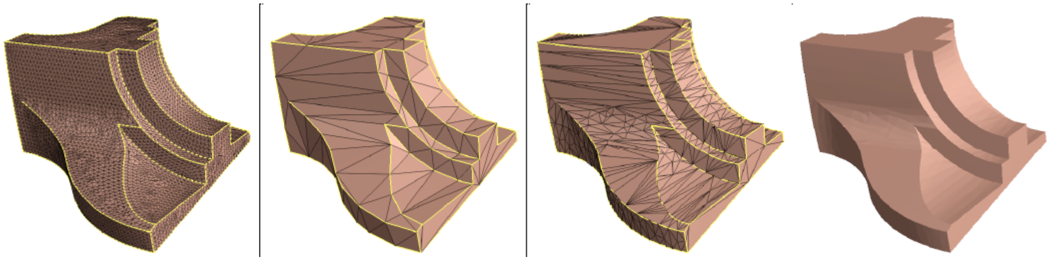
- Objects with only a few pixels on screen rendered as simplified models
- Creation of simplified models



LoD

- Progressive meshes – mesh loading
- http://research.microsoft.com/en-us/um/people/hoppe/proj/pm/
- From coarse mesh to finest using vertex split, created using edge collapse

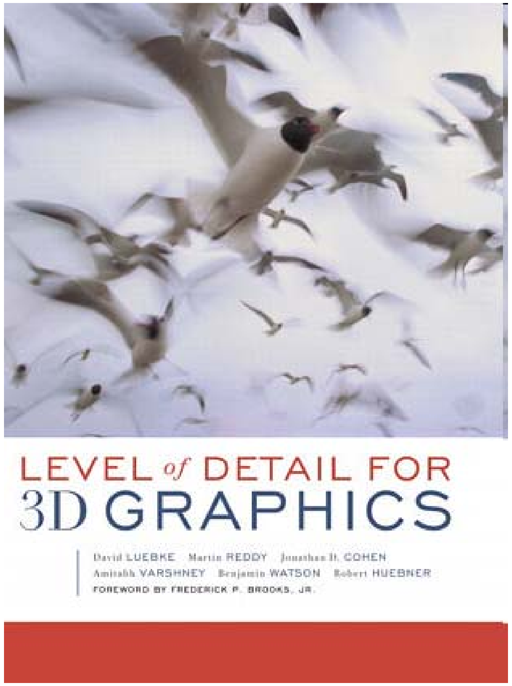




[Hugues Hoppe]

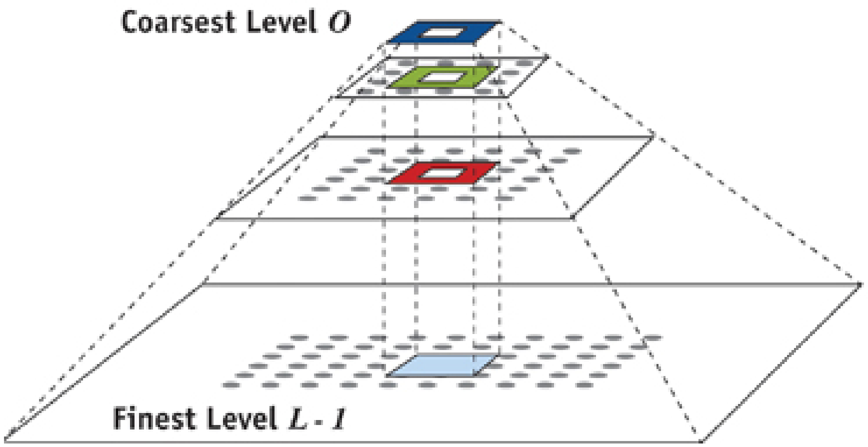
LoD sources

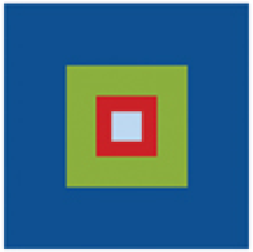
- http://meshlab.sourceforge.net/
- http://assimp.sourceforge.net/
- http://jsomers.com/vipm_demo/meshsimp.html
- http://lodbook.com/

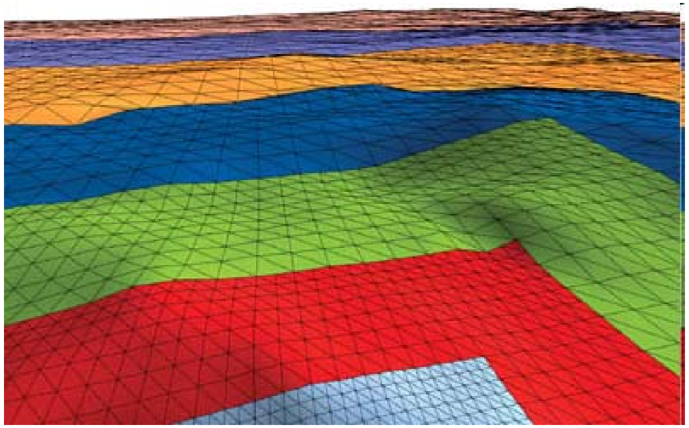

LEVEL of DETAIL FOR
3D GRAPHICS
David LUEBKE Martin REDDY Jonathan D. COHEN
Amitabh VARSHNEY Benjamin WATSON Robert HUEBNER
FOREWORD BY FREDERICK P. BROOKS, JR.

Terrain LoD

- Terrain – 2D elevation (height) map
- Geometry clipmaps
- Using prefiltered mipmapped height maps




Top View of Terrain

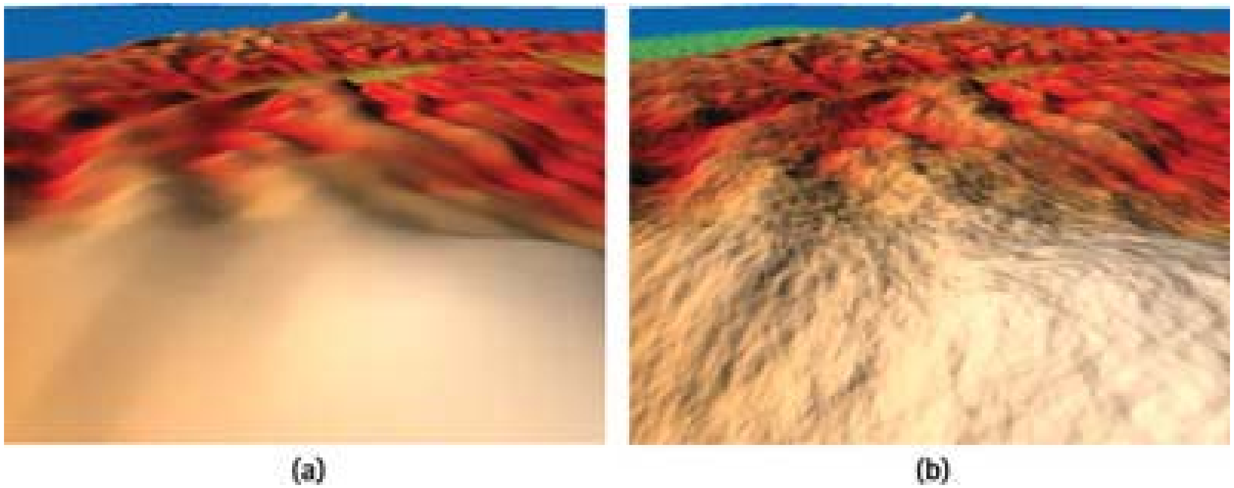


Terrain LOD

- Blending heights on levels boundary

$$\alpha_x = \text{clamp}\left(\left(x - v_x - \left(\frac{n-1}{2} - w - 1\right)\right) w, \ 0, \ 1\right),$$

- GPU, shaders implementation
- http://developer.nvidia.com/node/19



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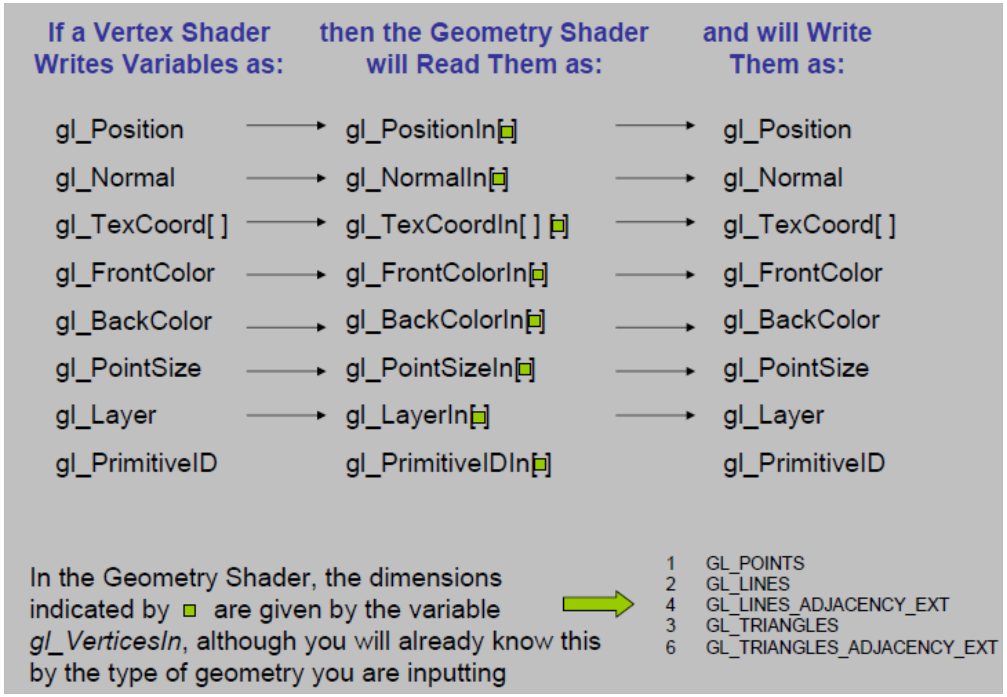
Geometry shader

- Using GPU for creating triangles

```
#version 120
#extension GL_EXT_geometry_shader4 : enable
void main(void)
{
        int i;
        //Pass-thru!
        for(i=0; i< gl_VerticesIn; i++)
        {
                gl_Position = gl_PositionIn[i];
                EmitVertex();
        }
        EndPrimitive();

        //New piece of geometry! We just swizzle the x and y terms
        for(i=0; i< gl_VerticesIn; i++)
        {
                gl_Position = gl_PositionIn[i];
                gl_Position.xy = gl_Position.yx;
                EmitVertex();
        }
        EndPrimitive();
}
```

Geometry shader

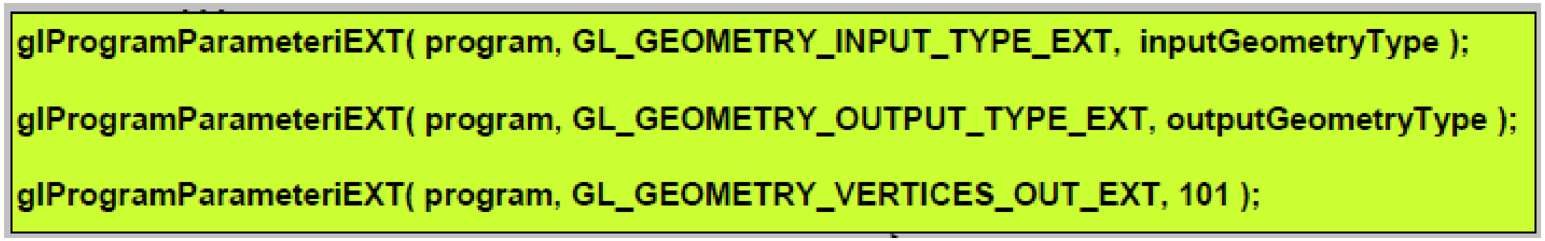
- Adjacency arguments for glBegin
  - GL_LINES_ADJACENCY_EXT
  - GL_LINE_STRIP_ADJACENCY_EXT
  - GL_TRIANGLES_ADJACENCY_EXT
  - GL_TRIANGLE_STRIP_ADJECENCY_EXT



If a Vertex Shader Writes Variables as:	then the Geometry Shader will Read Them as:	and will Write Them as:
gl_Position	gl_PositionIn[🟩]	gl_Position
gl_Normal	gl_NormalIn[🟩]	gl_Normal
gl_TexCoord[ ]	gl_TexCoordIn[ ] [🟩]	gl_TexCoord[ ]
gl_FrontColor	gl_FrontColorIn[🟩]	gl_FrontColor
gl_BackColor	gl_BackColorIn[🟩]	gl_BackColor
gl_PointSize	gl_PointSizeIn[🟩]	gl_PointSize
gl_Layer	gl_LayerIn[🟩]	gl_Layer
gl_PrimitiveID	gl_PrimitiveIDIn[🟩]	gl_PrimitiveID

In the Geometry Shader, the dimensions indicated by 🟩 are given by the variable *gl_VerticesIn*, although you will already know this by the type of geometry you are inputting

1	GL_POINTS
2	GL_LINES
4	GL_LINES_ADJACENCY_EXT
3	GL_TRIANGLES
6	GL_TRIANGLES_ADJACENCY_EXT



```
glProgramParameteriEXT( program, GL_GEOMETRY_INPUT_TYPE_EXT,  inputGeometryType );

glProgramParameteriEXT( program, GL_GEOMETRY_OUTPUT_TYPE_EXT, outputGeometryType );

glProgramParameteriEXT( program, GL_GEOMETRY_VERTICES_OUT_EXT, 101 );
```

Tesselation shaders

- GL_ARB_tessellation_shader, OpenGL 4.0
- Tessellation control shader transforms per-vertex data and sets per-patch tess. levels
- Tessellation evaluation shader computes position and attributes of new generated vertices

```
// VERTEX SHADER
in vec4 position;
uniform sampler2D terrain;

void main(void)
{
        vec2 texcoord = position.xy;
        float height = texture(terrain, texcoord).a;
        vec4 displaced = vec4(position.x, position.y, height, 1.0);
        gl_Position = displaced;
}
```

Tesselation shaders

```
// TESSELATION CONTROL SHADER
// The main function is called for each vertex in the patch.
// gl_InvocationID identifies which vertex is being processed.
layout(vertices = 4) out;
uniform vec2 screen_size;
uniform mat4 mvp;
uniform float lod_factor;

bool offscreen(vec4 vertex)
{
  if(vertex.z < -0.5) return true;
  return any(lessThan(vertex.xy, vec2(-1.7)) ||
             greaterThan(vertex.xy, vec2(1.7)));
}

vec4 project(vec4 vertex)
{
  vec4 result = mvp * vertex;
  result /= result.w;
  return result;
}

vec2 screen_space(vec4 vertex)
{
  return (clamp(vertex.xy, -1.3, 1.3)+1) * (screen_size*0.5);
}

float level(vec2 v0, vec2 v1)
{
  return clamp(distance(v0, v1)/lod_factor, 1, 64);
}
```

```
void main()
{
  if(gl_InvocationID == 0)
  {
    vec4 v0 = project(gl_in[0].gl_Position);
    vec4 v1 = project(gl_in[1].gl_Position);
    vec4 v2 = project(gl_in[2].gl_Position);
    vec4 v3 = project(gl_in[3].gl_Position);

    if(all(bvec4(offscreen(v0), offscreen(v1), offscreen(v2), offscreen(v3))))
    {
      gl_TessLevelInner[0] = gl_TessLevelInner[1] = 0;
      gl_TessLevelOuter[0] = gl_TessLevelOuter[1] = 0;
      gl_TessLevelOuter[2] = gl_TessLevelOuter[3] = 0;
    }
    else
    {
       vec2 ss0 = screen_space(v0);
       vec2 ss1 = screen_space(v1);
       vec2 ss2 = screen_space(v2);
       vec2 ss3 = screen_space(v3);
       float e0 = level(ss1, ss2);
       float e1 = level(ss0, ss1);
       float e2 = level(ss3, ss0);
       float e3 = level(ss2, ss3);
       gl_TessLevelInner[0] = mix(e1, e2, 0.5);
       gl_TessLevelInner[1] = mix(e0, e3, 0.5);
       gl_TessLevelOuter[0] = e0;
       gl_TessLevelOuter[1] = e1;
       gl_TessLevelOuter[2] = e2;
       gl_TessLevelOuter[3] = e3;
    }
  }
  gl_out[gl_InvocationID].gl_Position = gl_in[gl_InvocationID].gl_Position;
}
```

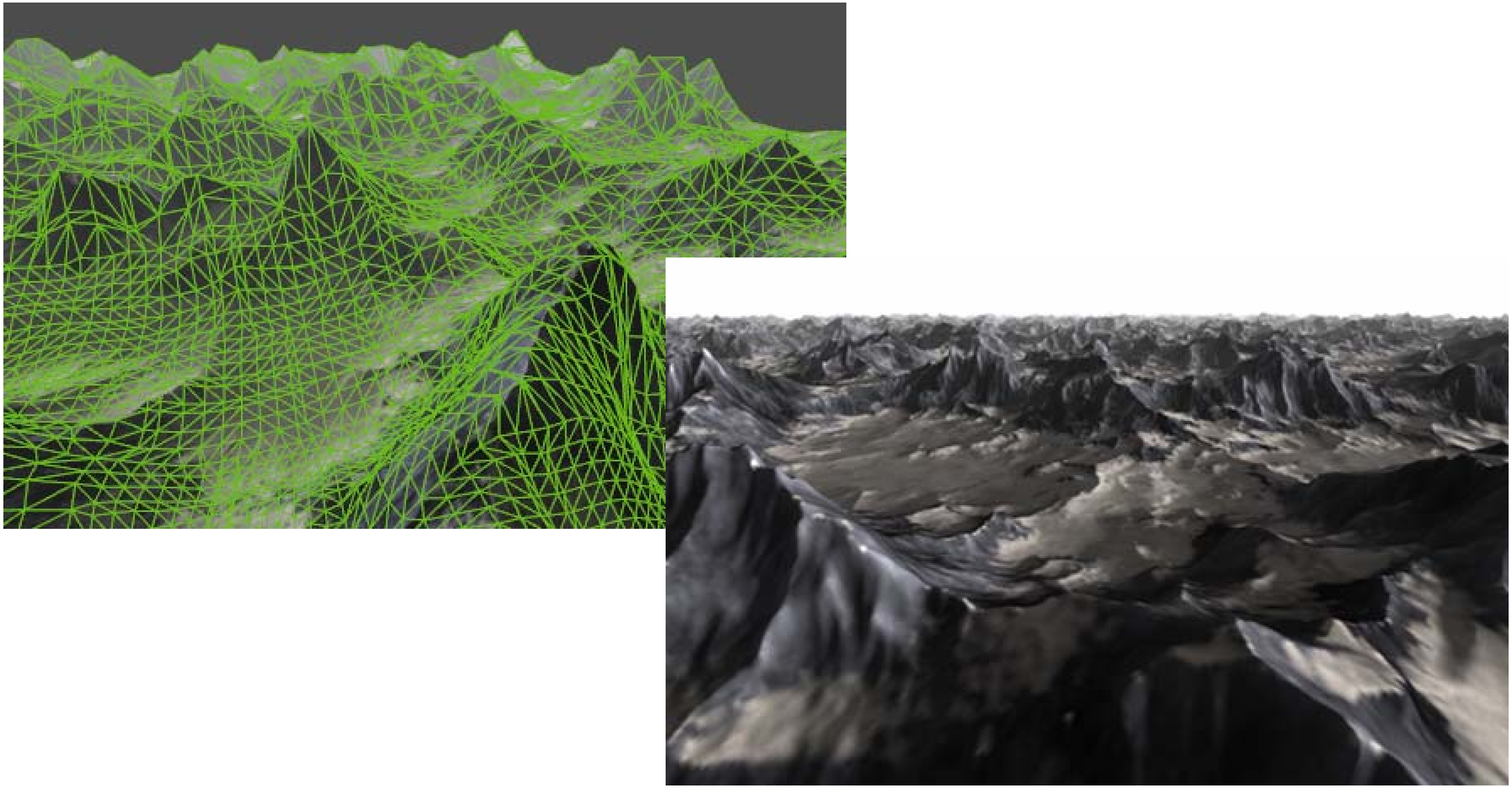
Tesselation shaders

http://codeflow.org/entries/2010/nov/07/opengl-4-tessellation/

```
// TESSELATION EVALUATION SHADER
// The Evaluation main function is called once for each vertex
of the tessellated output.
// The coordinate is given as UV vector relative to the positions
of the patches control points.
layout(quads, fractional_odd_spacing, ccw) in;
out vec2 texcoord;
out float depth;
uniform sampler2D terrain;
uniform mat4 mvp;

void main()
{
   float u = gl_TessCoord.x;
   float v = gl_TessCoord.y;

   vec4 a = mix(gl_in[1].gl_Position, gl_in[0].gl_Position, u);
   vec4 b = mix(gl_in[2].gl_Position, gl_in[3].gl_Position, u);
   vec4 position = mix(a, b, v);
   texcoord = position.xy;
   float height = texture(terrain, texcoord).a;
   gl_Position = mvp * vec4(texcoord, height, 1.0);
   depth = gl_Position.z;
}
```

```
// FRAGMENT SHADER
in vec2 texcoord;
in float depth;
out vec4 fragment;
uniform sampler2D diffuse;
uniform sampler2D terrain;
uniform sampler2D noise_tile;
vec3 incident = normalize(vec3(1.0, 0.2, 0.5));
vec4 light = vec4(1.0, 0.95, 0.9, 1.0) * 1.1;

void main()
{
   vec3 normal = normalize(texture(terrain, texcoord).xyz);
   vec4 color = texture(diffuse, texcoord);
   float noise_factor = texture(noise_tile, texcoord*32).r+0.1;
   float dot_surface_incident = max(0, dot(normal, incident));
   color = color * light * noise_factor * (max(0.1, dot_surface_incident)+0.05)*1.5;
   fragment = mix(color, color*0.5+vec4(0.5, 0.5, 0.5, 1.0), depth*2.0);
}
```

Tesselation shaders

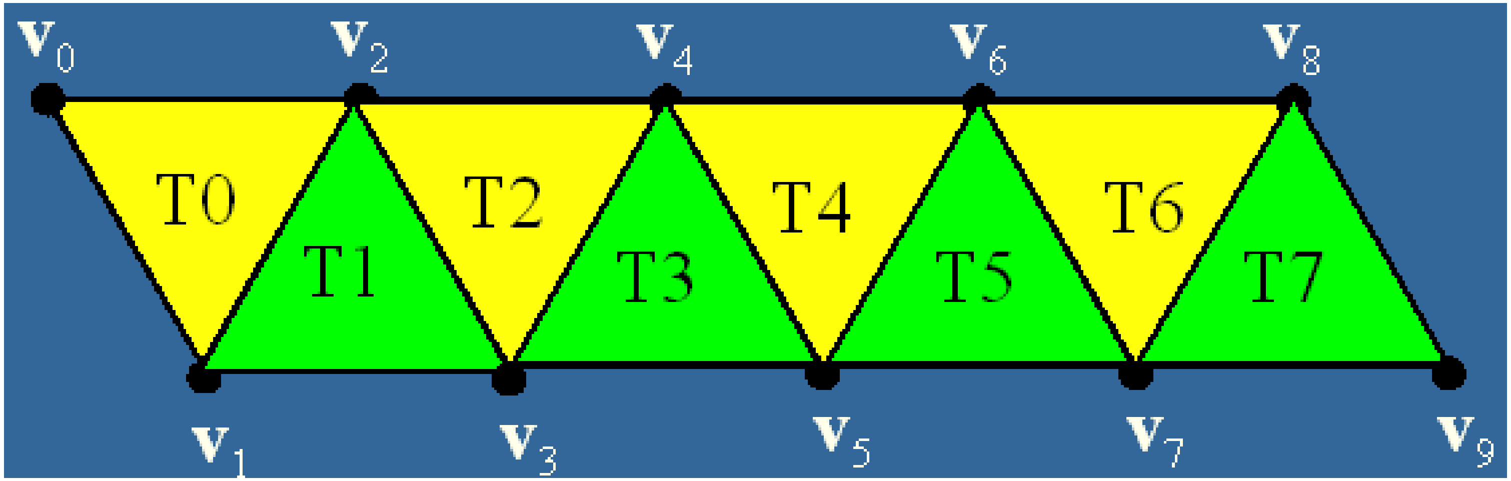


Optimalizing geometry

- Reduce number of API calls and state changes!
- Define triangles with fewer amount of data
- Create as large vertex arrays as possible
- Use small number of textures
- Use geometry instancing
- Use VBO

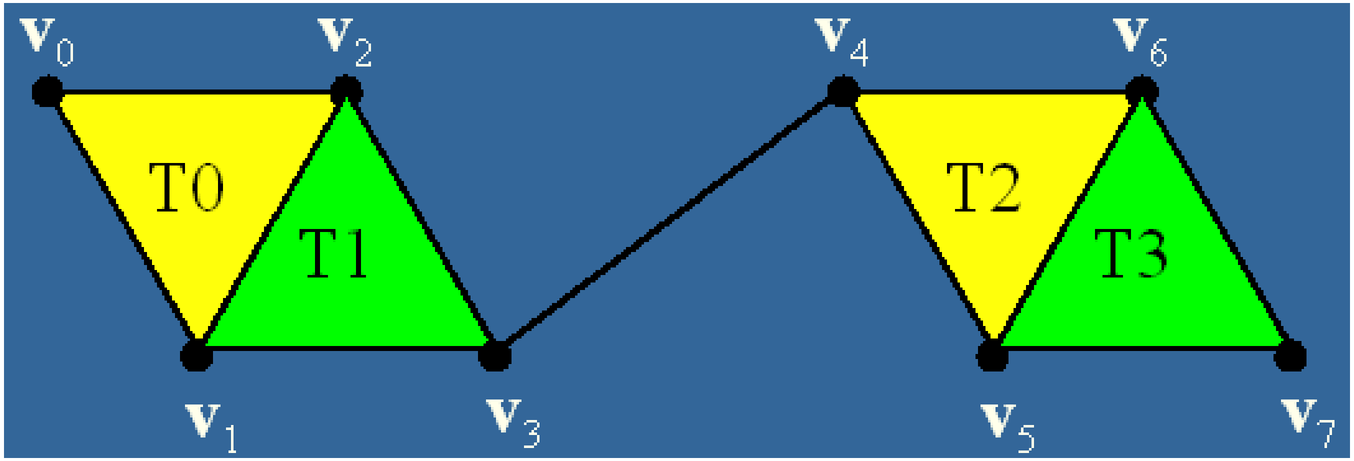
Polygon strips

- Reducing number of data for representing triangles
- Can increase number of buffers, API calls
- OpenGL maintain orientation



Polygon strips

- Non-connected strips – swaps 0,1,2,3,3,4,4,5,6,7



- Creation
  - Manually, own code
  - NVTriStripper

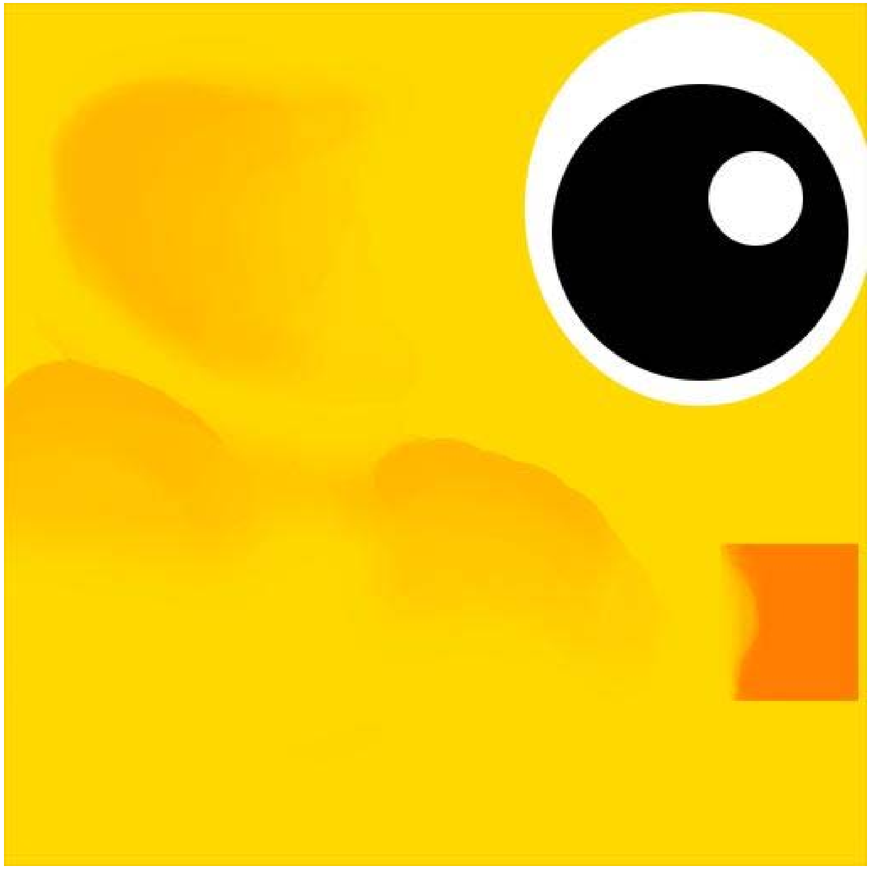
Geometry instancing

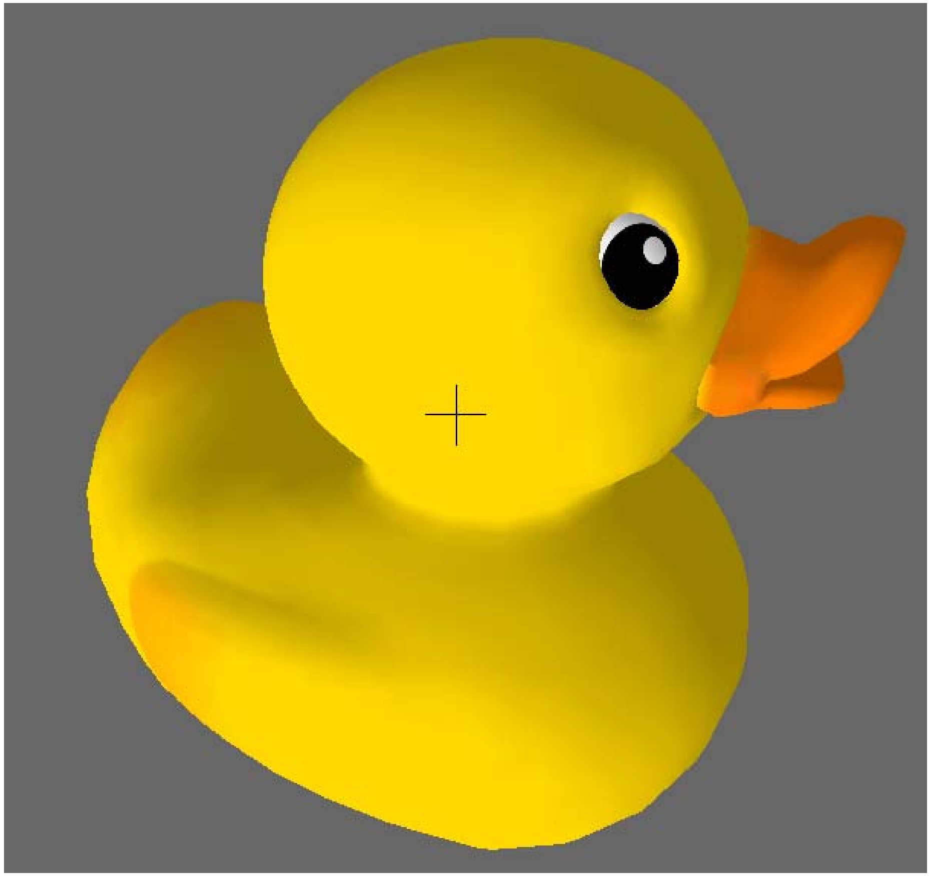
- Scene with many same objects (trees, people)
- Display lists
- VBOs
- Dynamic update of VBO data
- GPU geometry instancing
  - *GL_EXT_draw_instanced*
  - Draw VBO using *glDrawArraysInstancedEXT(GLenum mode, GLint start, GLsizei count, GLsizei primcount), glDrawElementsInstancedEXT(GLenum mode, GLsizei count, GLenum type, const GLvoid *indices, GLsizei primcount)*
  - In vert. shader, use *gl_InstanceID*, to get which instance is processed
  - Based on instance ID, use different transformation, attributes, ...

Texture atlas

- Combination of as many textures as possible
- Combination of meshes to one set of vertex arrays
- Recomputation of texture coordinates
- Reducing number of state changes (texture switches)
- No tiling, color bleeding (mipmap, filtering)

Texture atlas





Collision detection

- Testing intersection
  - Camera-object
  - Object-object
  - Triangle-line
  - Triangle-triangle
- Using acceleration structures
  - BSP tree
  - Bounding volumes tree
  - Octree
- Physics engines

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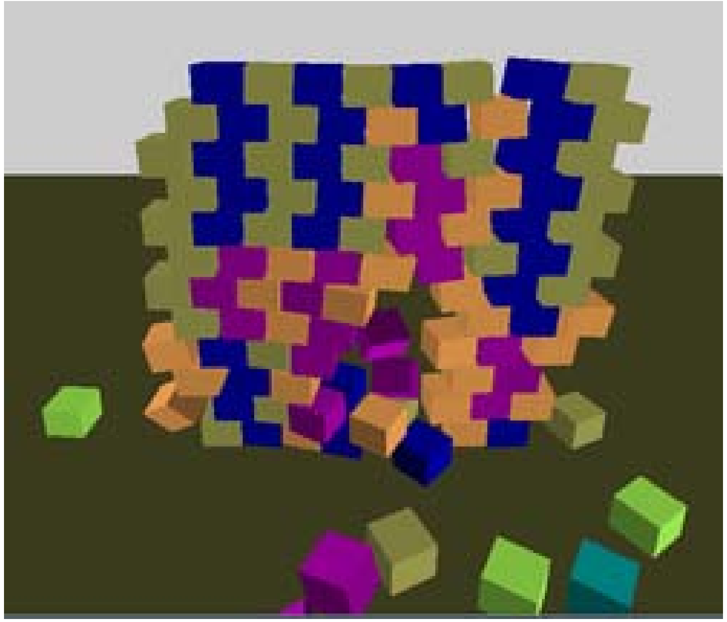

Physics engines

- C/C++ libraries for computation of collisions, simulations, movements, forces, clothes, ...
- Many platforms: PS3, Win, Linux, MAC OS X, 3DS max, ..
- Bullet
  - Open source, free to use
  - http://bulletphysics.org/
  - GPU acceleration
  - Grand Theft Auto IV, Red Dead Redemption, ..
- Havok
  - Proprietary/Shareware
  - http://www.havok.com/
  - Fallout 3, StarCraft II, Half Life 2, The Elder Scrolls IV: Oblivion, ..
- PhysX
  - Proprietary realtime physics engine
  - GPU and PPU acceleration
  - http://www.nvidia.com/object/physx_new.html
  - Mafia II, Batman: Arkham Asylum, Metro 2033, ..

Questions?