# Real-time Graphics

## 2. Buffer Objects, FBO

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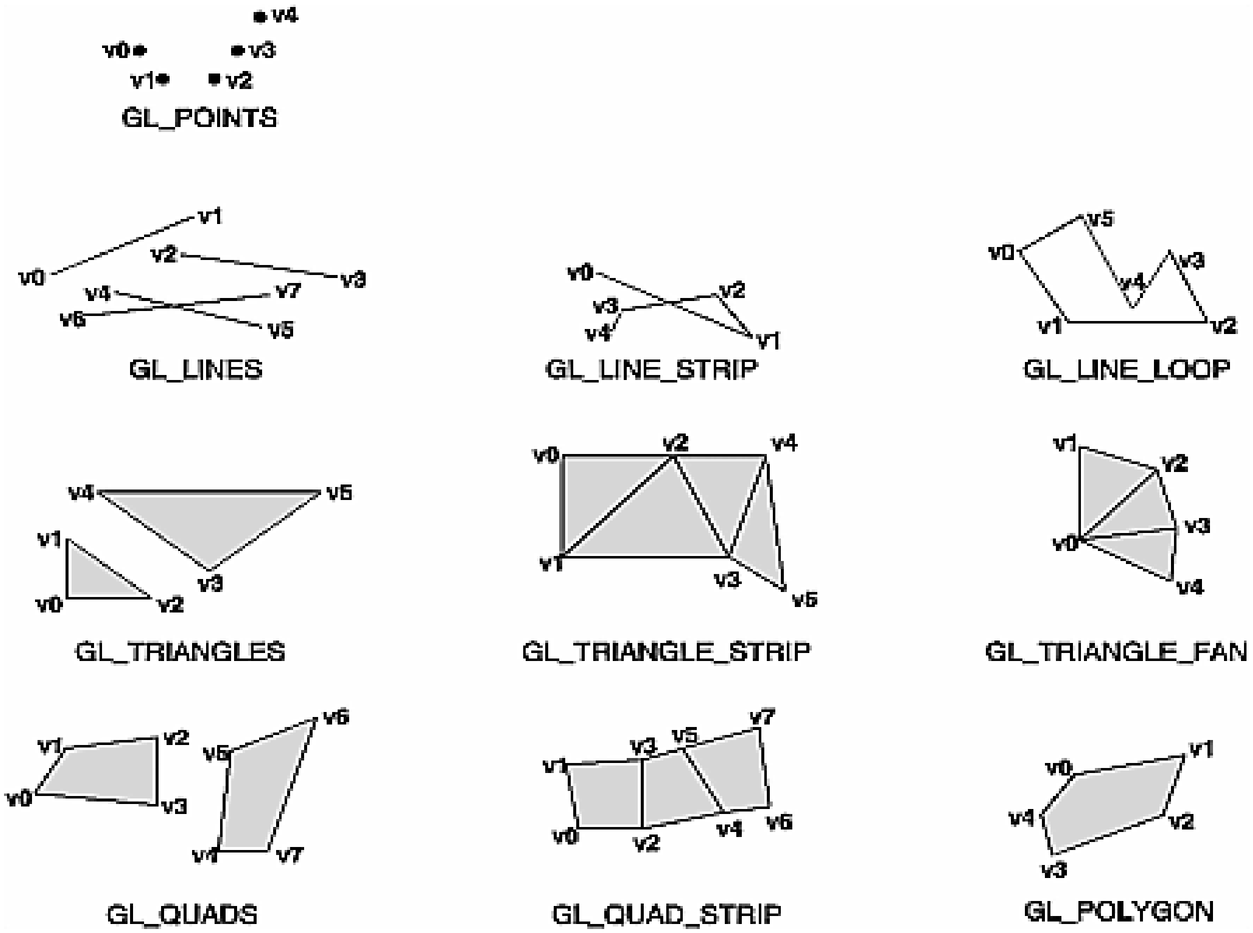
# Geometry entry



# Geometry entry

- Intermediate Mode
  - *glBegin* / *glEnd* block
  - Each vertex given by *glVertex*
  - Slow, Depreciated
- Vertex arrays
  - Lots of data in large buffers
  - Minimalization of function calls
  - Buffers for vertex attributes (coordinates, normals, texture coordinates, ...)

# Display lists

- Group of commands stored for later execution in compiled form
- No later evaluation and data transmitting
- Efficient for static data
- Can be shared between contexts
- After compilation, can’t be modified - bad for dynamic data
- Client related commands can’t be stored (vertex arrays)

# Vertex arrays

- Solve sharing of vertex data between polygons, separate vertex and polygon
- Arrays of vertex attributes – coordinates, normals, colors, tex. coordinates, ...
- Arrays of indices for creating polygons
- Arrays are in client memory
- Arrays are transmitted each frame

# Setting vertex arrays

- Set data in client's memory as vertex attributes
- *void glVertexPointer (GLint size, GLenum type, GLsizei stride, const GLvoid* pointer)*
  - *size* - 2, 3, 4
  - *type* - GL_SHORT, GL_INT, GL_FLOAT, GL_DOUBLE
  - *stride* - byte offset between consecutive vertices
  - *pointer* - data in client memory
- *glColorPointer*, *glTexCoordPointer*, ...
- Enable: *void glEnableClientState (GLenum cap)*

# Vertex arrays – OGL 2.0

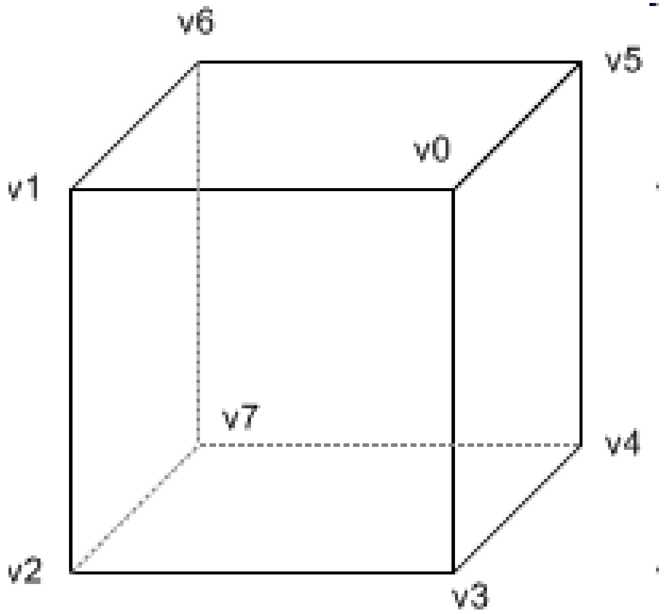
- Passing arbitrary vertex attributes to vertex shader
- *void glVertexAttribPointer(GLuint index, GLint size, GLenum type, GLboolean normalized, GLsizei stride, const GLvoid* pointer)*
  - *index* - location of attribute in shader program
  - *size* - number of components – 1,2,3,4
  - *type* - data type of each component
  - *normalized* - integer values mapped to [-1,1] or [0,1]
  - *stride* - byte offset between consecutive attributes
  - *pointer* – data
- Enable: *void glEnableVertexAttrib(GLuint index)*

# Vertex arrays drawing

- *void glDrawArrays (GLenum mode, GLint first, GLsizei count)*
  - *mode* - GL_POINTS, GL_LINE_STRIP, GL_LINE_LOOP, GL_LINES, GL_TRIANGLE_STRIP, GL_TRIANGLE_FAN, GL_TRIANGLES, GL_QUAD_STRIP, GL_QUADS, GL_POLYGON
  - *first* - specifies starting index
  - *count* - specifies the number of used indices
- *void glDrawElements (GLenum mode, GLsizei count, GLenum type, const GLvoid *indices)*
  - *type* - type of each index in indices array - GL_UNSIGNED_BYTE, GL_UNSIGNED_SHORT, GL_UNSIGNED_INT
  - *indices* - array of indices to be used for primitives

# Vertex arrays

```
GLfloat vertices[] = {1,1,1,    -1,1,1,  -1,-1,1,   1,-1,1,            // v0-v1-v2-v3
                      1,-1,-1,  1,1,-1,  -1,1,-1,  -1,-1,-1};          // v4-v5-v6-v7
GLfloat colors[] = {1,1,1,   0,1,1,  0,0,1,  1,0,1,                    // c0-c1-c2-c3
                    1,0,0,   1,1,0,   0,1,0,  0,0,0};                  // c4-c5-c6-c7
GLubyte indices[] = {0,1,2,3,  0,3,4,5,  0,5,6,1,                      // f0-f1-f2
                     1,6,7,2,   7,4,3,2,  4,7,6,5};                    // f3-f4-f5

// activate and specify pointers to vertex arrays
glEnableClientState(GL_VERTEX_ARRAY);
glVertexPointer(3, GL_FLOAT, 0, vertices);
glEnableClientState(GL_COLOR_ARRAY);
glColorPointer(3, GL_FLOAT, 0, colors);

// draw a cube
glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, indices);

// deactivate vertex arrays after drawing
glDisableClientState(GL_VERTEX_ARRAY);
glDisableClientState(GL_COLOR_ARRAY);
```



# Vertex arrays – OGL 2.0

```
GLfloat vertices[] = {1,1,1,   -1,1,1,  -1,-1,1,   1,-1,1,  1,-1,-1,  1,1,-1,  -1,1,-1,  -1,-1,-1};
GLfloat colors[] = {1,1,1,  0,1,1,  0,0,1,  1,0,1,  1,0,0,   1,1,0,   0,1,0,  0,0,0};
GLubyte indices[] = {0,1,2,3,  0,3,4,5,  0,5,6,1,  1,6,7,2,   7,4,3,2,   4,7,6,5};

// get location, index of attributes in shader
GLuint vertexLoc = glGetAttribLocation(programID, "InVertex");
GLuint colorLoc = glGetAttribLocation(programID, "InColor");

// activate and specify pointers to vertex attribute arrays
glEnableVertexAttrib(vertexLoc);
glVertexAttribPointer(vertexLoc, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), vertices);
glEnableVertexAttrib(colorLoc);
glVertexAttribPointer(colorLoc, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), colors);

// draw a cube
glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, indices);

// deactivate vertex arrays after drawing
glDisableVertexAttrib(vertexLoc);
glDisableVertexAttrib(colorLoc);
```

```
attribute vec4 InVertex;
attribute vec3 InColor;
void main(void)
{
  gl_Position = gl_ModelViewProjectionMatrix * InVertex;
  gl_FrontColor = vec4(InColor, 1.0);
}
```

# OpenGL buffer objects

- Unified framework for work with buffers containing data of various types, server manages best location for data
- Each buffer object is represented by identifier, “name” – GLuint
- *void glGenBuffers{ARB} (GLsizei n, GLuint* bufs)*
  - generate *n* buffer object “names” (IDs)
  - *bufs* – array of size *n* for new buffer IDs
- *void glDeleteBuffers{ARB} (GLsizei n, const GLuint* bufs)*
  - delete *n* “named” buffer objects, *bufs* is array of IDs

# Current buffer object

- Only one active buffer objects of given type at a time
- Setting active buffer object with ID = *bufID*
- *void glBindBuffer{ARB} (GLenum target, GLuint bufID)*
    - *target* – type of active buffer:
        - GL_ARRAY_BUFFER
        - GL_ELEMENT_ARRAY_BUFFER
        - GL_PIXEL_PACK_BUFFER, GL_PIXEL_UNPACK_BUFFER
        - GL_UNIFORM_BUFFER
        - GL_TRANSFORM_FEEDBACK_BUFFER
        - ...

# Buffer object data

- Creates and initializes memory for active buffer object's data, fills memory with given data
- *void glBufferData{ARB} ( GLenum target, GLsizeiptr size, const GLvoid *data, GLenum usage)*
  - *target*: GL_ARRAY_BUFFER, ...
  - *size* – number of bytes, size of data
  - *data* – client memory block to be copied into buffer object, NULL – no copying, just allocating
  - *usage*
    - GL_STREAM_DRAW, _READ, _COPY
    - GL_STATIC_DRAW, _READ, _COPY,
    - GL_DYNAMIC_DRAW, _READ, _COPY

# Modifying data

- Map content of buffer object to part of client’s memory for reading or writing
- *void* glMapBuffer{ARB} (GLenum target, GLenum access)*
  - *access* - GL_READ_ONLY, GL_WRITE_ONLY, GL_READ_WRITE
- Now application can read or modify data in client memory given by returned pointer

# Modifying data

- Finishing with modification, changes are written to buffer object
- *GLboolean glUnmapBuffer{ARB} (GLenum target)*
- Getting parameters of buffer object
- *void glGetBufferParameteriv{ARB} (GLenum target, GLenum value, GLint * data);*
  - *value* - GL_BUFFER_ACCESS, GL_BUFFER_MAPPED, GL_BUFFER_SIZE, or GL_BUFFER_USAGE
  - *data* – returned parameter value

# Vertex Buffer Objects

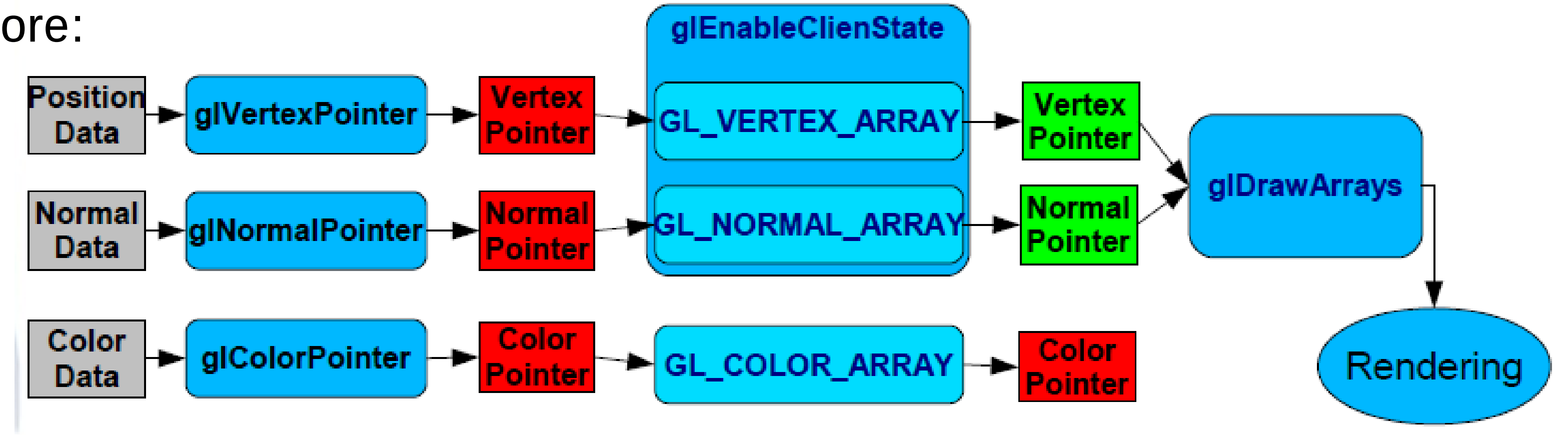
- Enhanced vertex arrays
- Vertex attributes and indices are copied to server memory only once as buffer objects
- Instead of vertex array or index array, buffer is attached
- Extension - GL_ARB_vertex_buffer_object
- From OpenGL 1.5
- Buffers can be shared between contexts

# Using VBO

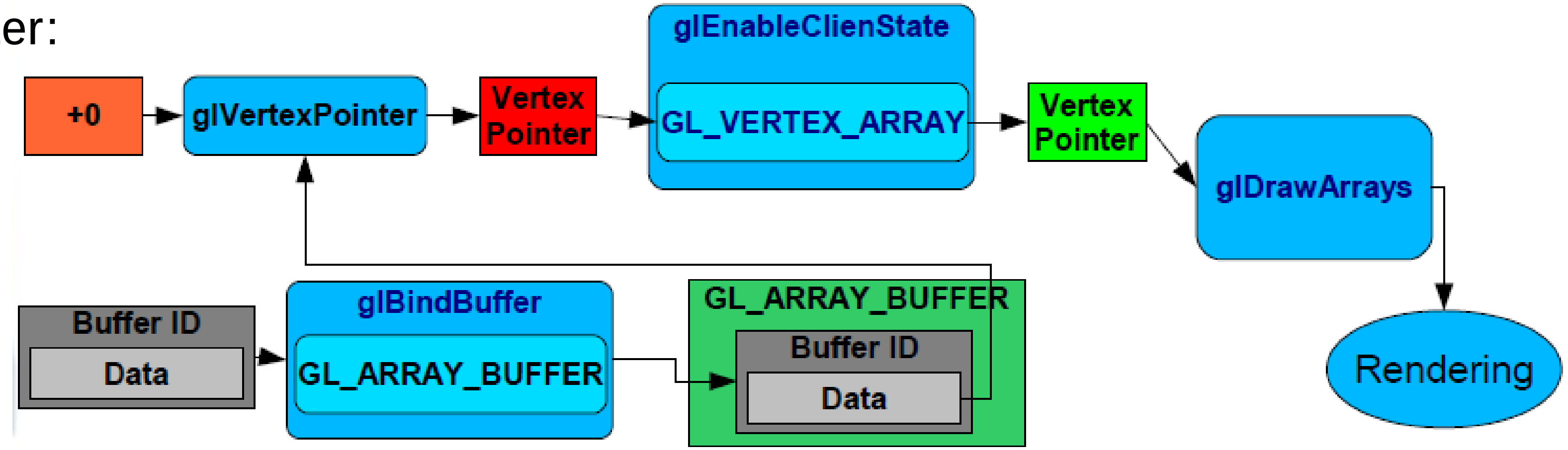
- Use vertex arrays as usual, instead of setting pointer to client memory, bind prepared buffer object and set pointer to 0
- Data from buffer will be used
- Before:
  - *glVertexPointer (3, GL_FLOAT, 0, vertices)*
- After:
  - *glBindBuffer (GL_ARRAY_BUFFER, uiID)*
  - *glVertexPointer (3, GL_FLOAT, 0, NULL)*

# Using VBO

Before:

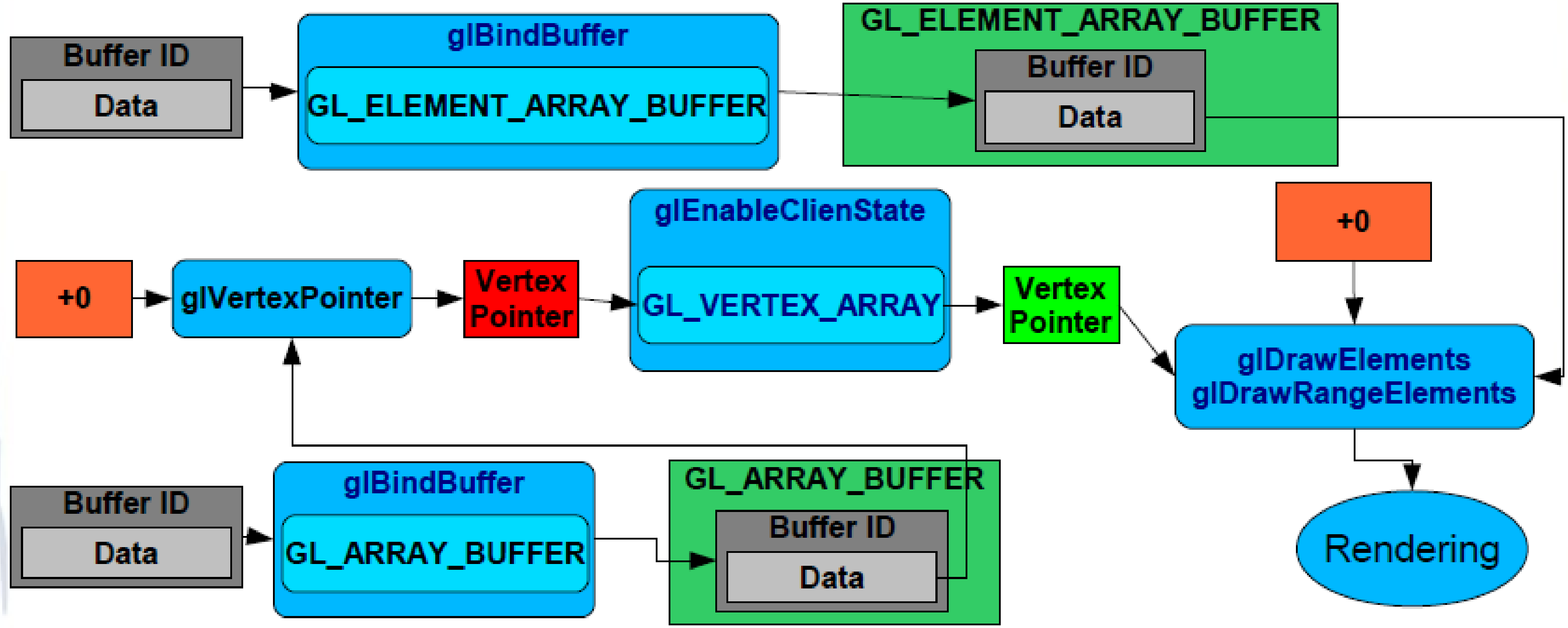


After:



# Drawing with VBO

- *glDrawElements* is retrieving indices from actual binded element buffer



# VBO example - init

```
GLfloat vertices[] = {1,1,1,   -1,1,1,  -1,-1,1,   1,-1,1, 1,-1,-1,  1,1,-1,  -1,1,-1,  -1,-1,-1};
GLfloat colors[] = {1,1,1,   0,1,1,  0,0,1,  1,0,1, 1,0,0,   1,1,0,   0,1,0,  0,0,0};
GLubyte indices[] = {0,1,2,3,  0,3,4,5,  0,5,6,1,  1,6,7,2,   7,4,3,2,  4,7,6,5};

// prepare used buffer objects, in init phase of application
// buffer object with coordinates
glGenBuffers(1, &g_uiCoordBuffer);
glBindBuffer(GL_ARRAY_BUFFER, g_uiCoordBuffer);
glBufferData(GL_ARRAY_BUFFER, 24 * sizeof(GLfloat), vertices, GL_STATIC_DRAW);

// buffer object with colors
glGenBuffers(1, &g_uiColorBuffer);
glBindBuffer(GL_ARRAY_BUFFER, g_uiColorBuffer);
glBufferData(GL_ARRAY_BUFFER, 24 * sizeof(GLfloat), colors, GL_STATIC_DRAW);

// buffer object with indices
glGenBuffers(1, &g_uiIndexBuffer);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, g_uiIndexBuffer);
glBufferData(GL_ELEMENT_ARRAY_BUFFER, 24 * sizeof(GLubyte), indices, GL_STATIC_DRAW);
```

# VBO example - draw

```
// activate and specify pointers to vertex arrays
glEnableClientState(GL_VERTEX_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER, g_uiCoordBuffer);
glVertexPointer(3, GL_FLOAT, 0, NULL);

glEnableClientState(GL_COLOR_ARRAY);
glBindBuffer(GL_ARRAY_BUFFER, g_uiColorBuffer);
glColorPointer(3, GL_FLOAT, 0, NULL);

// draw a cube
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, g_uiIndexBuffer);
glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, NULL);

// deactivate vertex arrays and VBO after drawing
glBindBuffer(GL_ARRAY_BUFFER, 0);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0);
glDisableClientState(GL_VERTEX_ARRAY);
glDisableClientState(GL_COLOR_ARRAY);
```

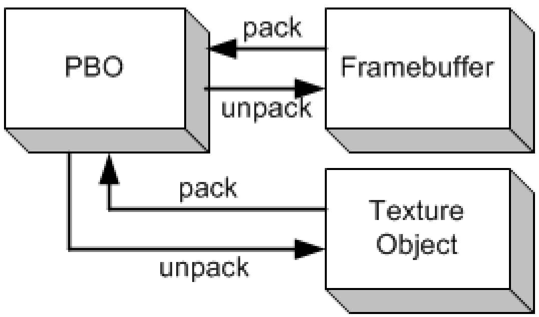
# VBO draw – OGL 2.0

```
// get location, index of attributes in shader
GLuint vertexLoc = glGetAttribLocation(programID, "InVertex");
GLuint colorLoc = glGetAttribLocation(programID, "InColor");

// activate and specify buffers to vertex attribute arrays
glEnableVertexAttrib(vertexLoc);
glBindBuffer(GL_ARRAY_BUFFER, g_uiCoordBuffer);
glVertexAttribPointer(vertexLoc, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), NULL);
glEnableVertexAttrib(colorLoc);
glBindBuffer(GL_ARRAY_BUFFER, g_uiColorBuffer);
glVertexAttribPointer(colorLoc, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), NULL);

// draw a cube
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, g_uiIndexBuffer);
glDrawElements(GL_QUADS, 24, GL_UNSIGNED_BYTE, NULL);

// deactivate vertex arrays after drawing
glDisableVertexAttrib(vertexLoc);
glDisableVertexAttrib(colorLoc);
glBindBuffer(GL_ARRAY_BUFFER, 0);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0);
```

```
// vertex shader using arbitrary VBO attributes
attribute vec4 InVertex;
attribute vec3 InColor;
void main(void)
{
  gl_Position = gl_ModelViewProjectionMatrix * InVertex;
  gl_FrontColor = vec4(InColor, 1.0);
}
```

# Pixel Buffer Objects

- Extension ARB_pixel_buffer_object
- Storing pixel data in buffer objects
- Fast pixel data transfer to and from a graphics card using DMA without CPU
- Replaces usage of client memory buffers for pack and unpack functions
- OpenGL 2.1



# Pixel Buffer Objects

- Unpack (read): *glBitmap*, *glColorSubTable*, *glColorTable*, *glCompressedTexImage1D*, *glCompressedTexImage2D*, *glCompressedTexImage*, *glCompressedTexSubImage1D*, *glCompressedTexSubImage2D*, *glCompressedTexSubImage3D*, *glConvolutionFilter1D*, *glConvolutionFilter2D*, *glDrawPixels*, *glPixelMapfv*, *glPixelMapuiv*, *glPixelMapusv*, *glPolygonStipple*, *glSeparableFilter2D*, *glTexImage1D*, *glTexImage2D*, *glTexImage3D*, *glTexSubImage1D*, *glTexSubImage2D*, *glTexSubImage3D*
- Pack (write): *glGetCompressedTexImage*, *glGetConvolutionFilter*, *glGetHistogram*, *glGetMinmax*, *glGetPixelMapfv*, *glGetPixelMapuiv*, *glGetPixelMapusv*, *glGetPolygonStipple*, *glGetSeparableFilter*, *glGetTexImage*, *glReadPixels*

```
// buffer object for storing pixel data
glGenBuffers(1, &g_uiPixelBuffer);
glBindBuffer(GL_PIXEL_PACK_BUFFER , uiPixelBuffer);
glBufferData(GL_PIXEL_PACK_BUFFER , 1024 * 768 * 4, 0, GL_STATIC_READ);
glReadPixels(0, 0, 1024, 768, GL_RGBA, GL_UNSIGNED_BYTE, 0);
glBindBuffer(GL_PIXEL_PACK_BUFFER, 0);
```

# Uniform buffer objects

- Sending uniform variables to shader programs, using block of uniforms
- Extension GL_ARB_uniform_buffer_object
- OpenGL 3.1

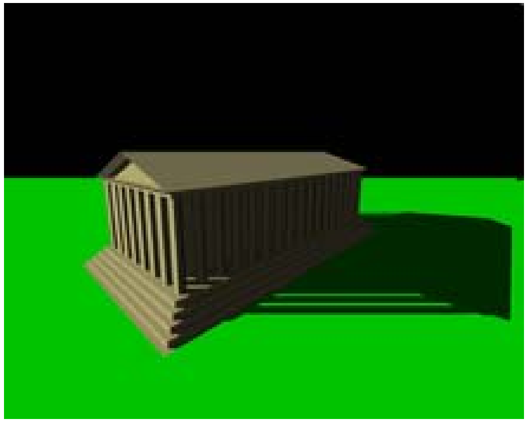
```
// Create and initialize
glGenBuffers(1, &UniformBufferTransformName);
glBindBuffer(GL_UNIFORM_BUFFER, UniformBufferTransformName);
glBufferData(GL_UNIFORM_BUFFER, GLsizei(sizeof(MVP)), &MVP[0][0], GL_DYNAMIC_DRAW);
glBindBuffer(GL_UNIFORM_BUFFER, 0);
UniformTransform = glGetUniformBlockIndex(ProgramName, "transform");
glUseProgram(ProgramName);
glBindBufferBase(GL_UNIFORM_BUFFER, 1, UniformBufferTransformName);
glUniformBlockBinding(ProgramName, UniformTransform, 1);
glUseProgram(0);

// Render, set the value of MVP uniform.
glUseProgram(ProgramName);
glBindBuffer(GL_UNIFORM_BUFFER, UniformBufferTransformName);
glBufferSubData(GL_UNIFORM_BUFFER, 0, GLsizei(sizeof(MVP)), &MVP[0][0]);
glBindBuffer(GL_UNIFORM_BUFFER, 0);
```

# Transformation feedback

- Primitives processed by a Vertex, Tesselation, Geometry Shader will be written to buffer objects
- Rasterizer can be switched off
- Fast processing of transformations
  - Update of particle systems
  - Tesselation
  - ...
- GL_EXT_transform_feedback

# Rendering to texture

- Fragment data copied also to textures
- Off-screen rendering to several buffers, textures
- Crucial for most effects, for multi-pass rendering
- Shadow maps, post-processing (HDR, gloom, filtering), reflections, SSAO, GPGPU, ......

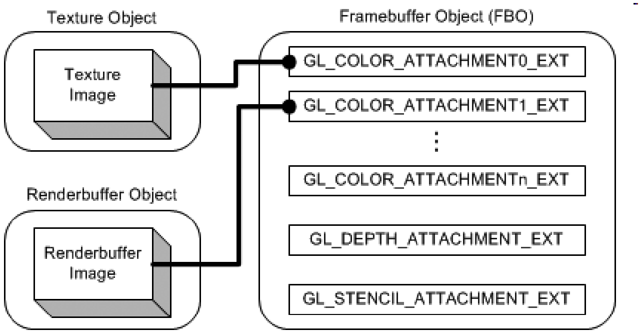


# Rendering to texture

- glReadPixels() -> glTexImage*()
  - slow, related to window size
  - PBO
- glCopyTexImage*()
  - better, related to window size
- glCopyTexSubImage*()
  - better, related to window size
- P-buffer
  - fast, new context must be created
  - Z-buffer only on Nvidia

# Framebuffer objects

- GL_ARB_framebuffer_object, OpenGL 3.0
- Additional non-displayable framebuffers
- Redirect the rendering output to the application-created framebuffer
- Framebuffer-attachable images:
  - textures and renderbuffers
- FBO contains a collection of rendering destinations:
  - color, depth, stencil



# FBO management

- Several framebuffer objects, each with integer identifier
- *void glGenFramebuffersEXT(GLsizei n, GLuint * framebuffers)*
  - generate *n* framebuffer object names
- *void glDeleteFramebuffersEXT(GLsizei n, const GLuint * framebuffers)*
  - delete named framebuffer objects
- *void glBindFramebufferEXT(GLenum target, GLuint framebuffer)*
  - bind a named framebuffer object
  - *target* must be GL_FRAMEBUFFER_EXT

# FBO texture images

- *void glFramebufferTexture2DEXT(GLenum target, GLenum attachment, GLenum textarget, GLuint texture, Glint level)*
  - *target* - must be GL_FRAMEBUFFER_EXT
  - *attachment*
    - GL_COLOR_ATTACHMENT0 .. n – n color textures
    - GL_DEPTH_ATTACHMENT – one depth texture
    - GL_STENCIL_ATTACHMENT – one stencil texture
  - *textarget*
    - GL_TEXTURE_2D
    - GL_TEXTURE_CUBE_MAP_POSITIVE_X, _Y, _Z,
    - GL_TEXTURE_CUBE_MAP_ NEGATIVE_X, _Y, _Z
  - *texture* - texture name generated by glGenTextures and set by glTexImage2D
  - *level* - mipmap level to attach from texture to attachment

# FBO renderbuffer images

- *void glGenRenderbuffersEXT (GLsizei n, GLuint * renderbuffs)*
  - generate renderbuffer object names
- *void glDeleteRenderbuffersEXT (GLsizei n, const GLuint * renderbuffs)*
  - delete named renderbuffer objects
- *void glBindRenderbufferEXT (GLenum target, GLuint renderbuffer)*
  - bind a named renderbuffer object
- *void glRenderbufferStorageEXT (GLenum target, GLenum internalformat, GLsizei width, GLsizei height)*
  - target - must be GL_RENDERBUFFER_EXT
  - internalformat - GL_RGBA4, GL_RGB565, GL_RGB5_A1, GL_DEPTH_COMPONENT16, 24, GL_STENCIL_INDEX8,…

# FBO renderbuffer images

- *void glFramebufferRenderbufferEXT ( GLenum target, GLenum attachment, GLenum renderbuffertarget, GLuint renderbuffer)*
  - target - must be GL_FRAMEBUFFER_EXT
  - attachment -
    - GL_COLOR_ATTACHMENT0..n
    - GL_DEPTH_ATTACHMENT
    - GL_STENCIL_ATTACHMENT
  - renderbuffertarget - must be GL_RENDERBUFFER_EXT
  - renderbuffer - name generated by glGenRenderbuffersEXT

# FBO status

- Validating current FBO
- *GLenum glCheckFramebufferStatusEXT (GL_FRAMEBUFFER_EXT)*
- Should be GL_FRAMEBUFFER_COMPLETE_EXT
- Rules for textures:
  - The width and height of framebuffer-attachable image must be not zero.
  - If an image is attached to a color attachment point, then the image must have a color-renderable internal format. (GL_RGBA, GL_DEPTH_COMPONENT, GL_LUMINANCE, etc)
  - If an image is attached to GL_DEPTH_ATTACHMENT_EXT, then the image must have a depth-renderable internal format. (GL_DEPTH_COMPONENT, GL_DEPTH_COMPONENT24_EXT, etc)
  - If an image is attached to GL_STENCIL_ATTACHMENT_EXT, then the image must have a stencil-renderable internal format. (GL_STENCIL_INDEX, GL_STENCIL_INDEX8_EXT, etc)
  - FBO must have at least one image attached.
  - All images attached a FBO must have the same width and height.
  - All images attached the color attachment points must have the same internal format.

# FBO example - init

```
// create a texture object
GLuint textureId;
glGenTextures(1, &textureId);
glBindTexture(GL_TEXTURE_2D, textureId);
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA8, TEXTURE_WIDTH, TEXTURE_HEIGHT, 0, GL_RGBA, GL_UNSIGNED_BYTE, 0);
glBindTexture(GL_TEXTURE_2D, 0);

// create a renderbuffer object to store depth info
GLuint rboId;
glGenRenderbuffersEXT(1, &rboId);
glBindRenderbufferEXT(GL_RENDERBUFFER_EXT, rboId);
glRenderbufferStorageEXT(GL_RENDERBUFFER_EXT, GL_DEPTH_COMPONENT, TEXTURE_WIDTH, TEXTURE_HEIGHT);
glBindRenderbufferEXT(GL_RENDERBUFFER_EXT, 0);

// create a framebuffer object
GLuint fboId;
glGenFramebuffersEXT(1, &fboId);
glBindFramebufferEXT(GL_FRAMEBUFFER_EXT, fboId);

// attach the texture to FBO color attachment point and the renderbuffer to depth attachment point
glFramebufferTexture2DEXT(GL_FRAMEBUFFER_EXT, GL_COLOR_ATTACHMENT0_EXT, GL_TEXTURE_2D, textureId, 0);
glFramebufferRenderbufferEXT(GL_FRAMEBUFFER_EXT, GL_DEPTH_ATTACHMENT_EXT, GL_RENDERBUFFER_EXT, rboId);

// check FBO status
GLenum status = glCheckFramebufferStatusEXT(GL_FRAMEBUFFER_EXT);
if(status != GL_FRAMEBUFFER_COMPLETE_EXT) fboUsed = false;
```

# FBO example - draw

```
// create a framebuffer object
glBindFramebufferEXT(GL_FRAMEBUFFER_EXT, fboId);

// set attachment to draw to
// if no color attachment is attached, call
//        glDrawBuffer(GL_NONE);
glDrawBuffer(GL_COLOR_ATTACHMENT0_EXT);

// ............ Render scene to texture here ............

// switch back to window-system-provided framebuffer
glBindFramebufferEXT(GL_FRAMEBUFFER_EXT, 0);
```

# Multiple render targets

- Extension GL_ARB_draw_buffers
- Multiple color attachments to store additional rendering info
- *glGetIntegerv(GL_MAX_COLOR_ATTACHMENTS_EXT, &maxColorAttachments)*
- *void glDrawBuffers(GLsizei n, const GLenum * bufs)*
  - *n* - number of color attachments to draw
  - *bufs* - array of color attachments
- Fragment shader - gl_FragData[i] is output variable that will be written to i-th draw attachment

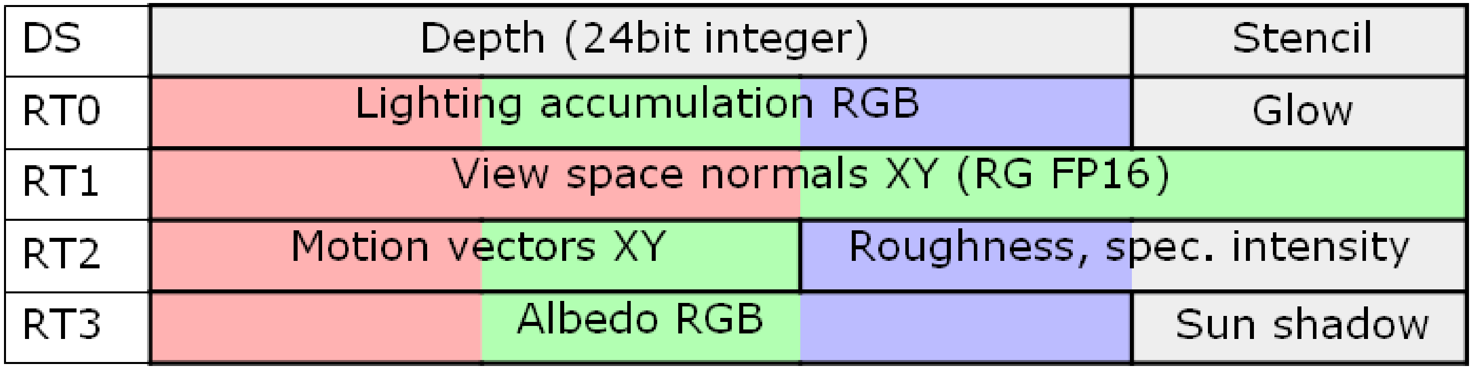
# MRT example

```
// create a framebuffer object
glBindFramebufferEXT(GL_FRAMEBUFFER_EXT, fboId);

// get number of color attachments
GLint maxColorAttachments;
glGetIntegerv(GL_MAX_COLOR_ATTACHMENTS_EXT, &maxColorAttachments);

// set attachments to draw to
// these attachments must be prepared as textures or renderbuffers
GLenum drawbuffers[3] = {GL_COLOR_ATTACHMENT0_EXT,
                         GL_COLOR_ATTACHMENT1_EXT,
                         GL_COLOR_ATTACHMENT2_EXT};
If (maxColorAttachments >= 3)
    glDrawBuffers(3, drawbuffers);
else
    glDrawBuffer(GL_COLOR_ATTACHMENT0_EXT);

// ............ Render scene to textures here ............

// switch back to window-system-provided framebuffer
glBindFramebufferEXT(GL_FRAMEBUFFER_EXT, 0);
```

```
// MRT fragment shader
void main(void)
{
   gl_FragData[0] = vec4(1.0, 0.0, 0.0, 1.0);
   gl_FragData[1] = vec4(0.0, 1.0, 0.0, 1.0);
   gl_FragData[2] = vec4(0.0, 0.0, 1.0, 1.0);
}
```

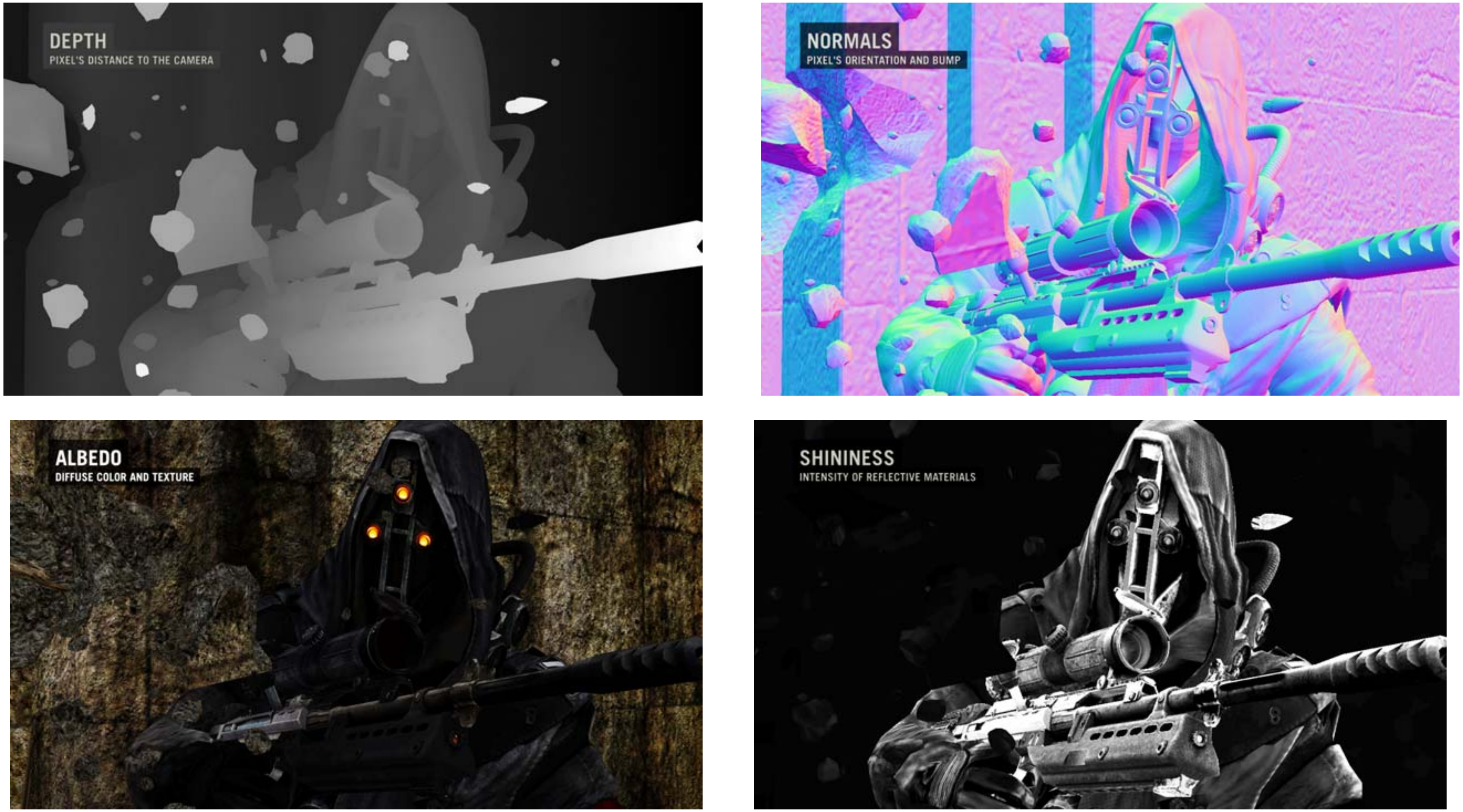
# MRT - Deferred shading

- Render scene to multiple render targets storing basic info about pixels (material, normal, ...) – G-buffer
- Compute shading only for window pixels in screen space
- Difficult transparency & HW anti-aliasing



| | | | | |
|---|---|---|---|---|
| DS | Depth (24bit integer) | | | Stencil |
| RT0 | Lighting accumulation RGB | | | Glow |
| RT1 | View space normals XY (RG FP16) | | | |
| RT2 | Motion vectors XY | | Roughness, spec. intensity | |
| RT3 | Albedo RGB | | | Sun shadow |

# Deferred shading


DEPTH
PIXEL'S DISTANCE TO THE CAMERA
NORMALS
PIXEL'S ORIENTATION AND BUMP
ALBEDO
DIFFUSE COLOR AND TEXTURE
SHININESS
INTENSITY OF REFLECTIVE MATERIALS

[Killzone 2]

# Deferred lighting

- Deferred lighting pipeline
  - In first pass, scene is rendered and only normal and depth data are stored in G-buffer
  - In second pass, lighting (+shadows) is computed using normal texture, reconstructed eye position and lights parameters in screen space. Output is texture containing diffuse and specular values of accumulated lighting for each pixel
  - In third pass, render scene again and combine computed diffuse and specular lighting from texture (from second pass ) with materials using some local lighting model. Post-process effects are added to result.
- No need for complicated G-buffer
- One more rendering pass for whole scene

# Deferred shaders – 1. pass

- Creating G-buffer – buffers with diffuse, specular material and normal data
- Can be extended with other material properties

```
// Deferred shading – 1.pass – vertex shader
varying vec4 N_eye;
varying vec2 vTexCoord;

void main(void)
{
  vTexCoord = vec2(gl_MultiTexCoord0);
  N_eye = vec4(gl_NormalMatrix * gl_Normal, 0.0);
  gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

```
// Deferred shading – 1.pass - fragment shader
uniform sampler2D diffuseMap;
varying vec4 N_eye;
varying vec2 vTexCoord;

void main(void)
{
  vec4 mat = texture2D(diffuseMap, vTexCoord);
  mat.a = gl_FrontMaterial.specular.r;
  gl_FragData[0] = mat;
  gl_FragData[1] = 0.5 * (normalize(N_eye) + 1);
  gl_FragData[1].a = gl_FrontMaterial.shininess / 255.0;
}
```

# Deferred shaders – 2. pass

- Rendering full-screen quad ([0,0,-1], [1,0,-1], [1,1,-1], [0,1,-1])
- Only one built-in light in scene, can be extended for many lights
  - Rendering light volumes for each light
  - Or rendering screen quad containing area of influence for each light
  - Rendering full-screen quad for directional light

```
// Deferred shading – 2.pass – vertex shader
varying vec2 vTexCoord;

void main(void)
{
   vTexCoord = vec2(gl_Vertex);
   gl_Position = 2 * gl_Vertex - 1;
}
```

# Deferred shaders – 2. pass

```
// Deferred shading – 2.pass - fragment shader
uniform sampler2D materialMap;
uniform sampler2D normalMap;
uniform sampler2D depthTexture;
uniform mat4 projMatrix;
uniform mat4 invProjMatrix;
uniform vec2 viewport_dim;
varying vec2 vTexCoord;

void main(void)
{
   // compute eye space position of fragment
   // from depth and window space position
   vec4 pos_ndc;
   pos_ndc.x = 2 * gl_FragCoord.x / viewport_dim.x – 1;
   pos_ndc.y = 2 * gl_FragCoord.y / viewport_dim.y – 1;
   pos_ndc.z = 2 * texture2D(depthTexture, vTexCoord).r - 1;
   if (pos_ndc.z == -1) discard;
   float T1 = projMat[2][2];
   float T2 = projMat[2][3];
   float E1 = projMat[3][2];
   vec4 pos_clip;
   pos_clip.w = T2 / (pos_ndc.z – T1 / E1);
   pos_clip.x = pos_ndc.x * pos_clip.w;
   pos_clip.y = pos_ndc.y * pos_clip.w;
   pos_clip.z = pos_ndc.z * pos_clip.w;
   vec4 pos_eye = invProjMat * pos_clip;
```

```
   // get vectors for lighting computation
   vec4 N_spec = texture2D(normalMap, vTexCoord);
   float shininess = 255 * N_spec.a; N_spec.a = 0;
   vec4 N_eye = normalize(2 * N_spec - 1);
   vec4 L_eye = normalize(gl_LightSource[0].position – pos_eye);
   vec4 V_eye = normalize(-pos_eye);

   // compute coefficients for components
   float diffuse = clamp(dot(L_eye, N_eye), 0.0, 1.0);
   vec4 R_eye = reflect(-L_eye, N_eye);
   float specular = sgn(diffuse)*pow(clamp(dot(R_eye, V_eye), 0.0, 1.0), shininess);

   // get material parameters from G-buffer texture
   vec4 mat = texture2D(materialMap, vTexCoord);

   // compute final color of fragment
   gl_FragColor = diffuse * gl_LightSource[0].diffuse * vec4(mat.xyz, 1) +
                  specular * gl_LightSource[0].specular * vec4(mat.a);
}
```

# Deferred lighting, shading

- Battlefield 3
- Crackdown
- Crysis 2
- Dead Space and Dead Space 2
- Dungeons
- Grand Theft Auto IV
- Halo Reach
- inFamous
- Killzone 2 and Killzone 3
- LittleBigPlanet
- Mafia 2
- Metro 2033
- Stalker: Shadow of Chernobyl, Clear Sky and Call of Prypiat
- Red Dead Redemption
- StarCraft II
- Assassin's Creed 3
- Almost every new game

# Questions?