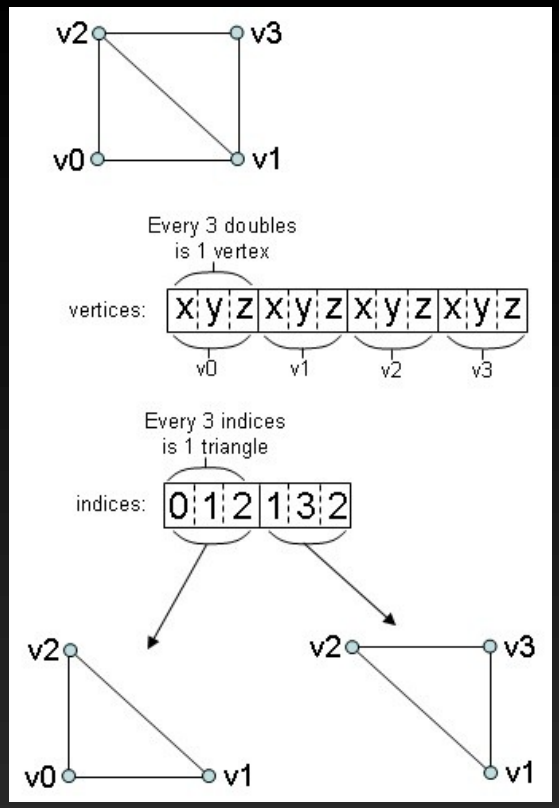
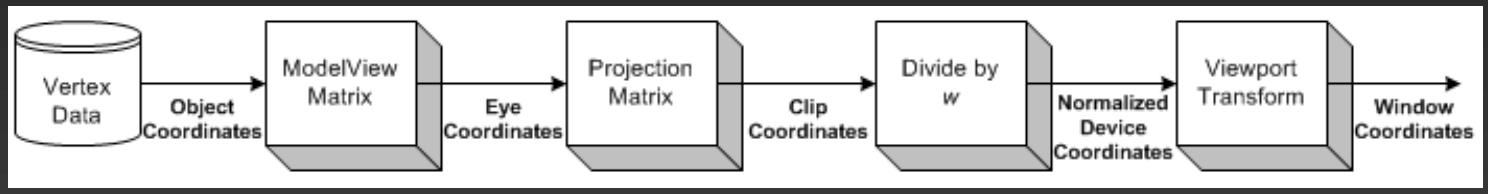
Opakování



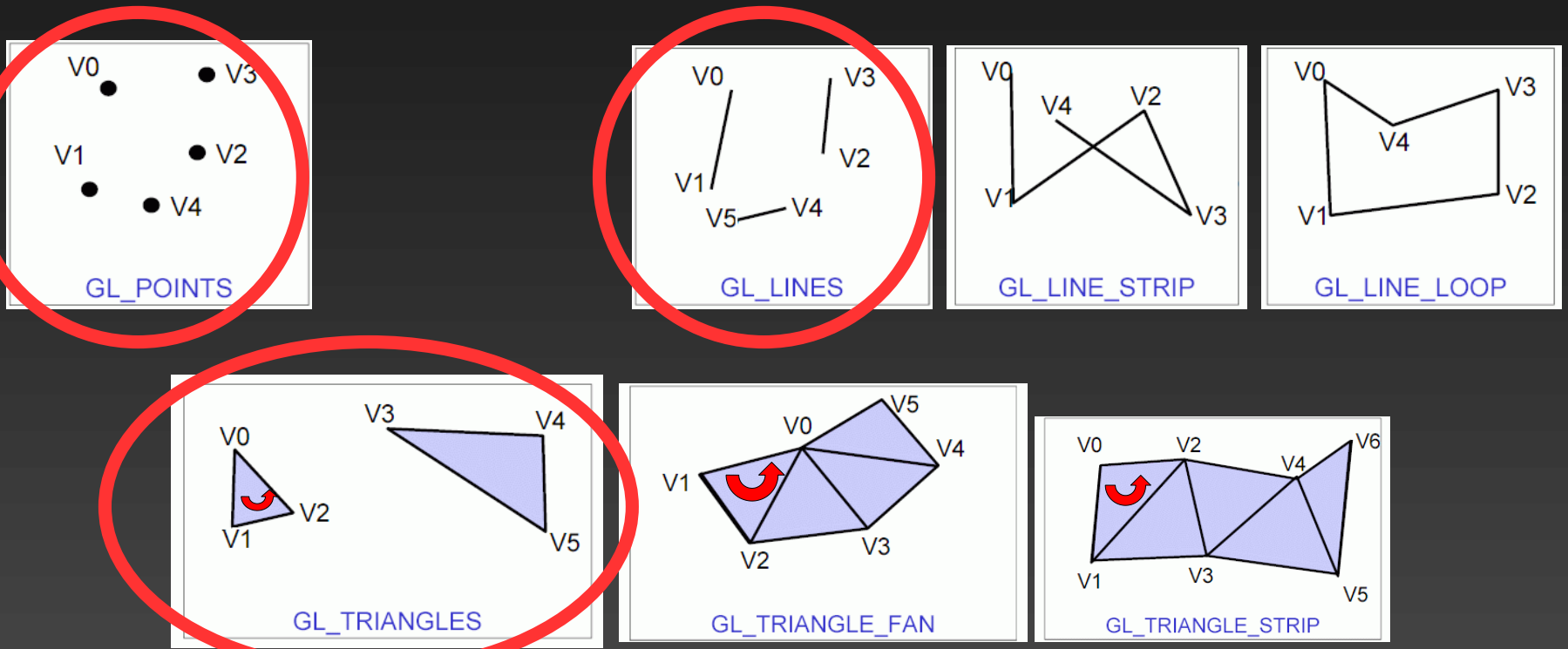
- Reprezentace
  - 3D rastr
  - obálka
    - vrchol (vertex)
    - hrana (edge)
    - ploška (face)
- 3D zobrazování



- načtení a transformace souřadnic zadaných vertexů
- rasterizace
- výpočet barvy fragmentu
- průhlednost a zakrývání podle Z

Geometrická primitiva

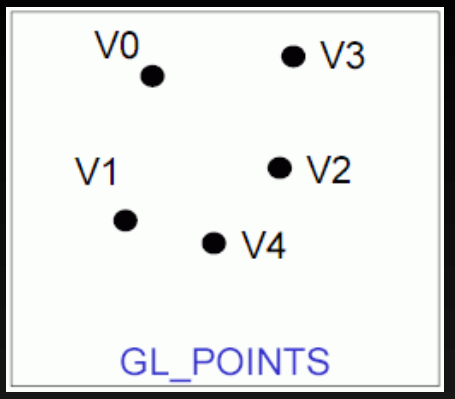
- 7 primitiv, zadávány pomocí vertexů [x,y,z,w]
- jen 3 primitiva skutečně v HW → překlad



Grafická primitiva

- Zadávány pomocí série vertexů
- Při nedostatečném počtu vertexů
  - nedefinované chování
    - nic se nevykreslí
    - nevykreslí se jen poslední část
    - (jakékoliv chybné chování)…

Vlastnosti bodů



- Teoreticky nekonečně malý, zadán jako *float*
  - několik bodů může vyústit v jeden pixel
    glPointSize(GLfloat)
  - standardně 1.0 (jeden pixel)
- Podle nastavení antialiasingu
  - čtverec
    glDisable(GL_POINT_SMOOTH)
  - kruh s rozmazaným okrajem (ne vždy podporováno)
    glEnable(GL_POINT_SMOOTH)
- Místo velkých (složitých) bodů – POINT SPRITE

Vlastnosti úseček

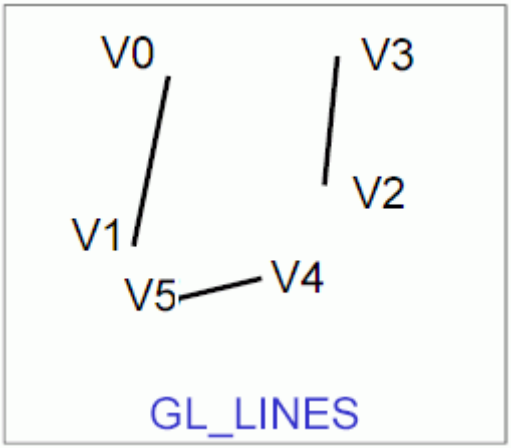
- Určené koncovými body
- Šířka čáry

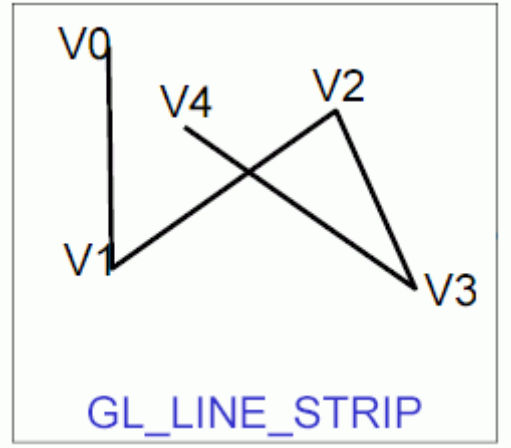
  glLineWidth(GLfloat)
  - standardně 1.0 (jeden pixel)

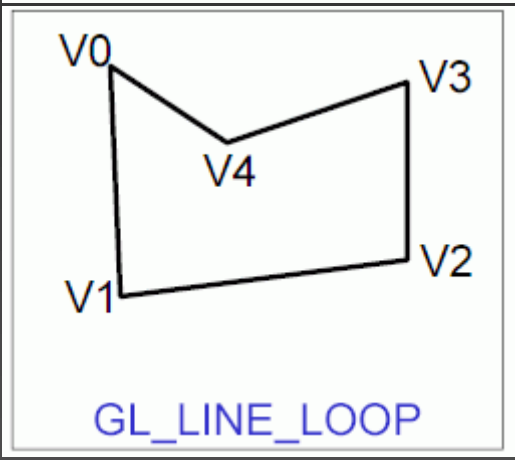
- Antialiasing určuje i zakončení
  - vertikální nebo horizontální konec

    glDisable(GL_LINE_SMOOTH)
  - jako natočený obdélník

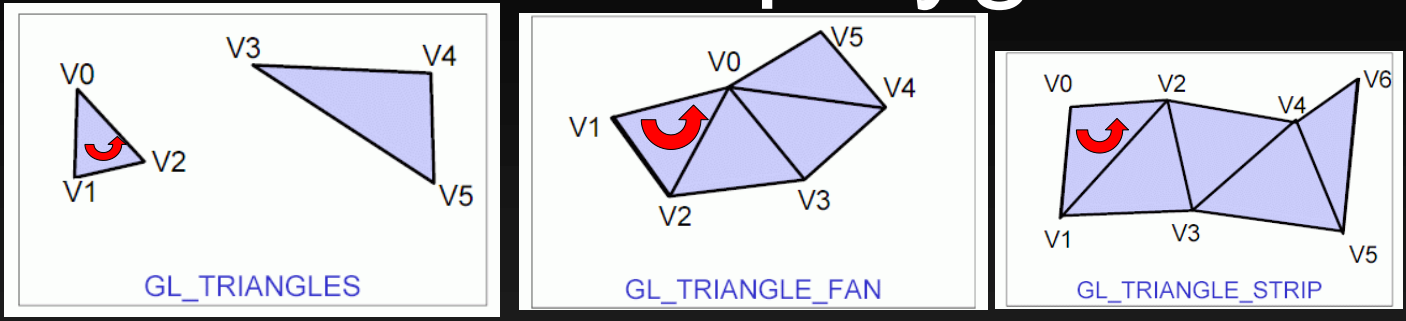
    glEnable(GL_LINE_SMOOTH)







Vlastnosti polygonů



- bez průsečíků, konvexní, v jedné rovině
  - případně teselace
- nejlépe trojúhelník
- Čelní a zadní strana
  - určené pořadím zadávání vertexů (prav. pravé ruky)

Vlastnosti polygonů

- ATRIBUTY pro jednotlivé vertexy
  - poloha, barva, normála, texturovací souřadnice...
- Čelní a zadní strana různé vlastnosti vykreslování
  - body, hrany, vyplněná plocha

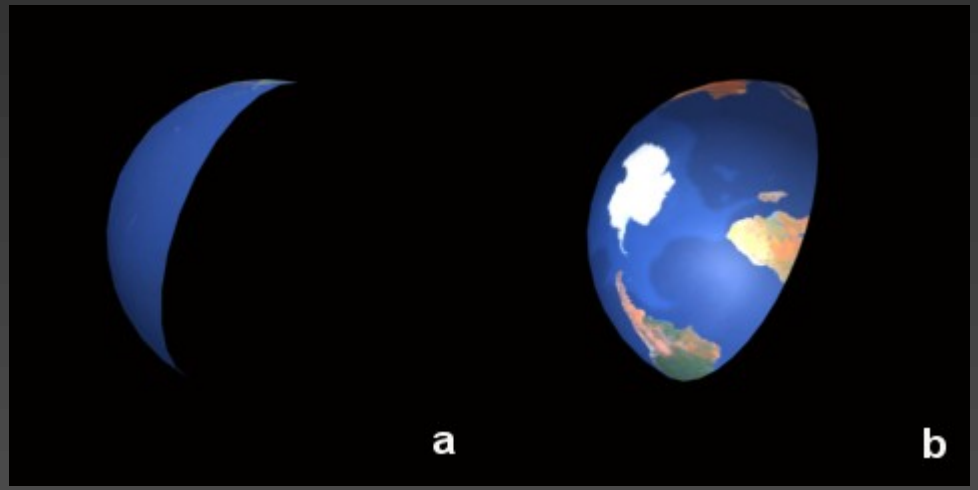
    glPolygonMode(face, mode)

    face: GL_FRONT_AND_BACK, GL_FRONT, GL_BACK

    mode: GL_POINT, GL_LINE, GL_FILL
  - ořez

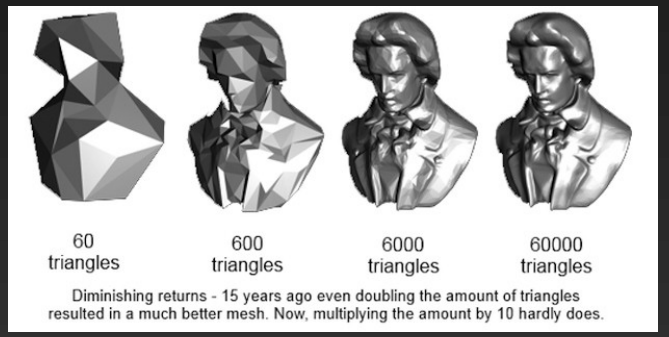
    glCullFace(mode)

    GL_FRONT_AND_BACK, GL_FRONT, GL_BACK

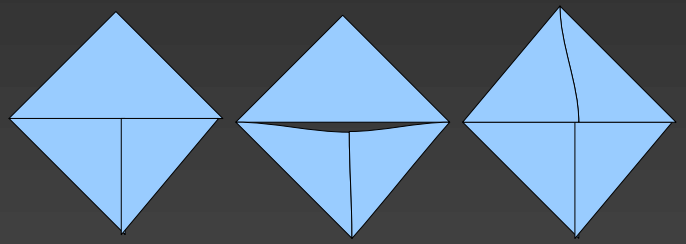


Doporučení

- Shodná orientace, CCW 
- Trojúhelníky (konvexní, vždy v rovině)
- Kompromis kvalita X množství polygonů
  - adaptivní dělení
    - podle křivosti
    - podle vzdálenosti
    - podle hrany
      - tečna - skalární součin se blíží nule



- Nepoužívat T křížení!

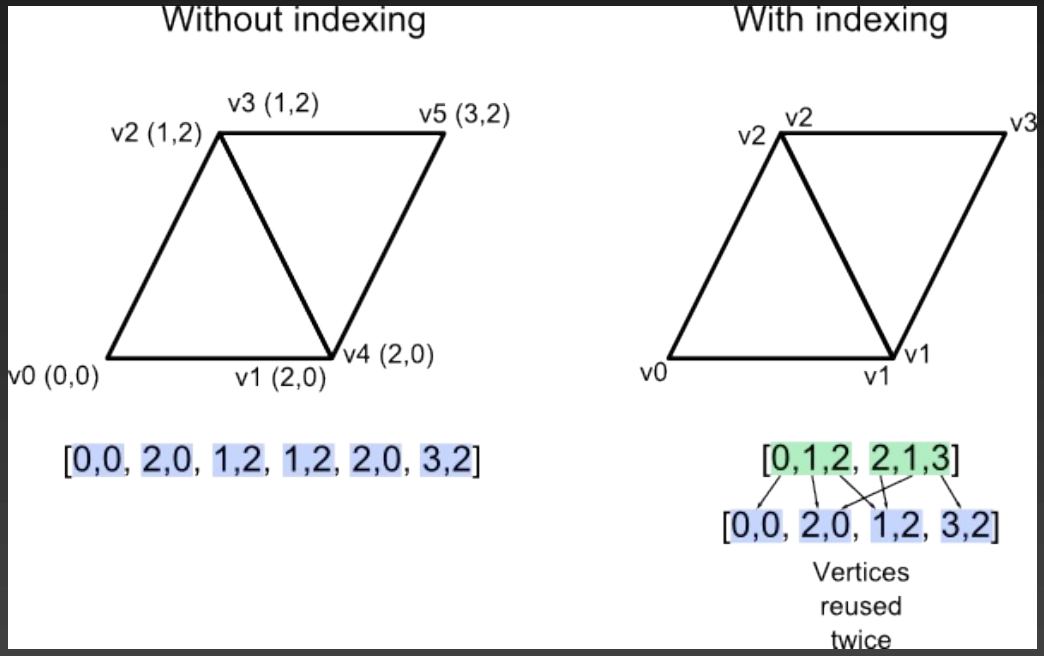


- Pro napojení použít přesně stejná čísla

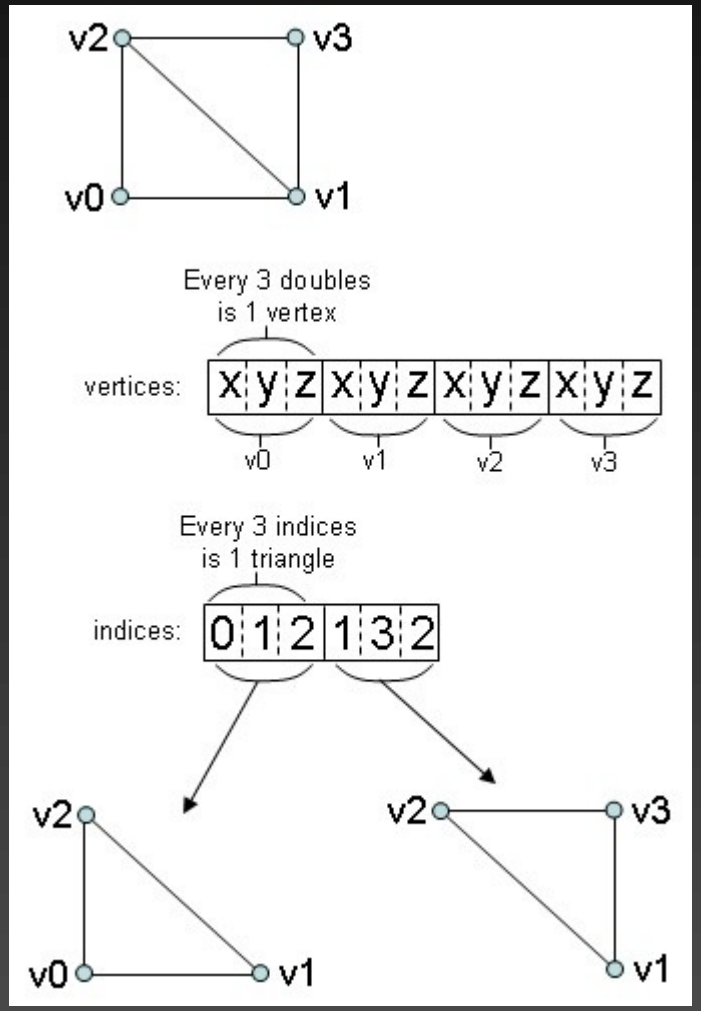
  $(a + b) + c \neq a + (b + c)$

Pole souřadnic vs. pole indexů souřadnic

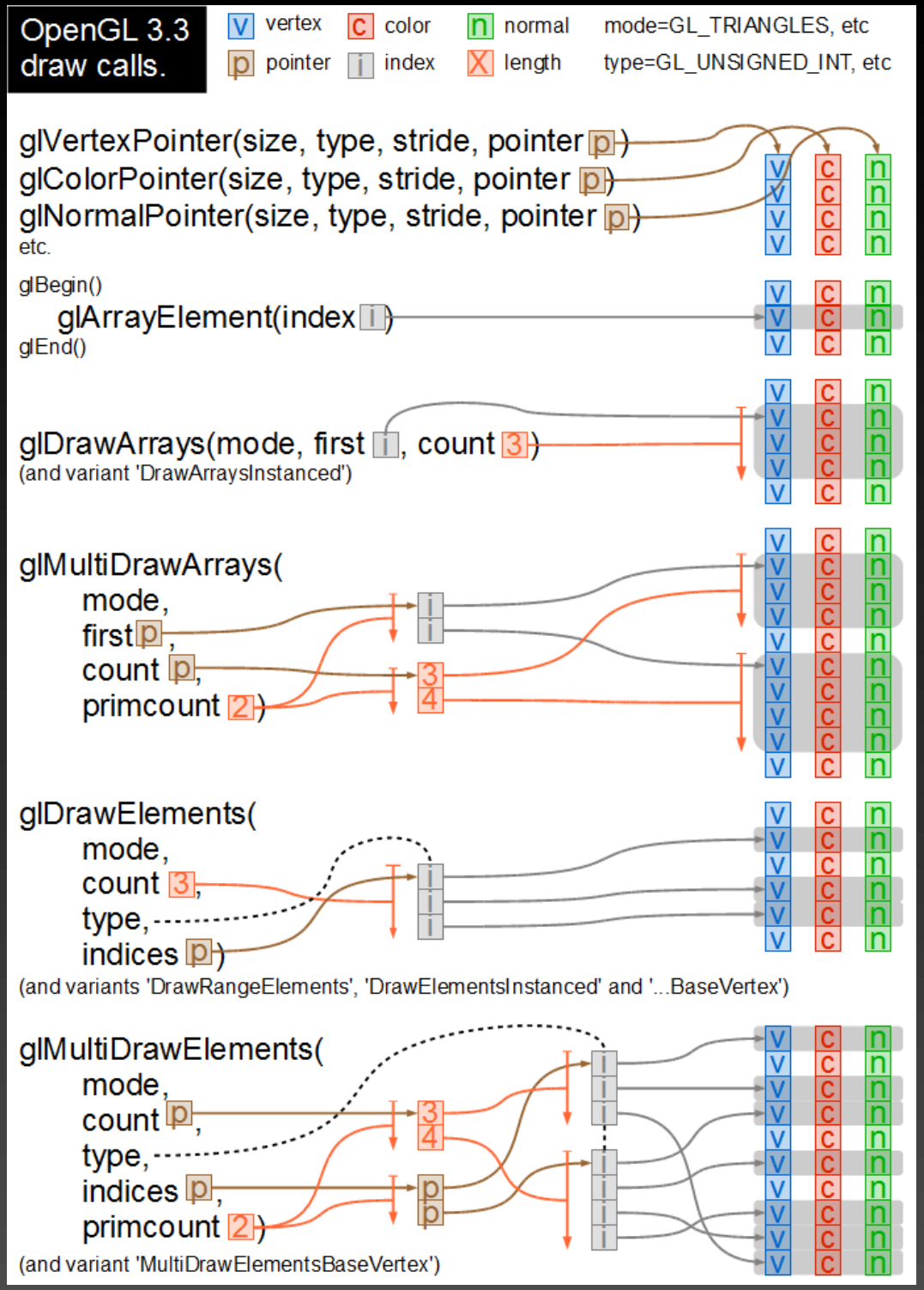
2D



3D

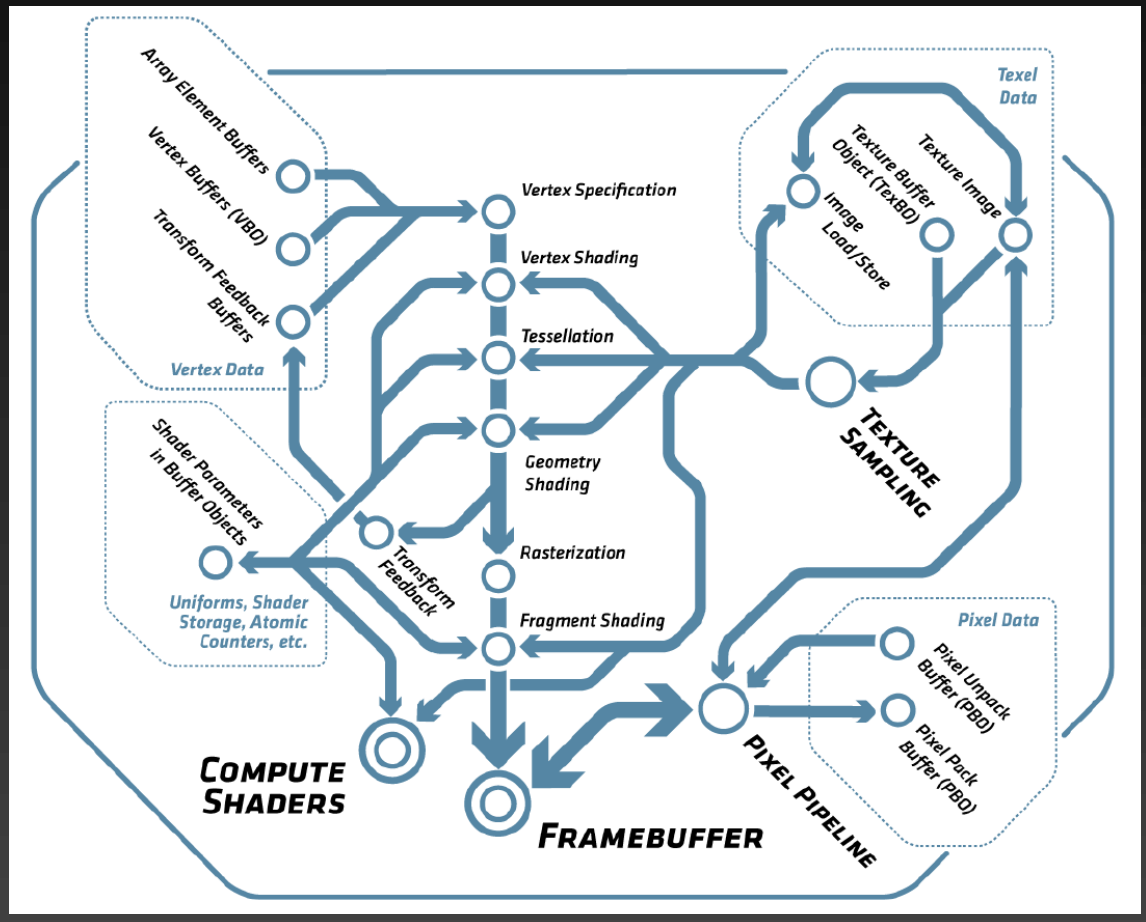


Některá vykreslovací volání



Using buffers for vertex data

- Used with shaders
- Linear memory in GPU
- Identified by ID
  - allocate
    glCreateBuffers(), glGenBuffers()
  - activate buffer
    glBindBuffer()
  - obtain data
    - fill to GPU
      glBufferData()
    - map CPU → GPU (slower)
      glMapBuffer()
  - draw
    glDrawArrays(), glDrawElements(),…
- Buffers are usually in GPU mem
  - fast
  - allocation can fail
    (no GPU mem paging)
  - changing data is not straightforward



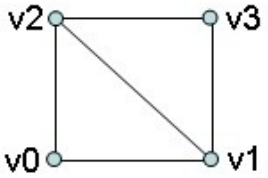
Vertex data

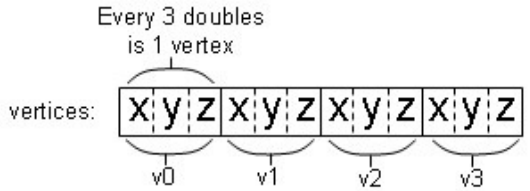
- Vertex Array Object = VAO
  - Container for grouping of attribute settings, placement etc.
  - Single rebinding by glBindVertexArray(VAO2) prepares vertex data of other object for draw
- Generic array
  - any data, YOU must specify how to interpret
    glVertexAttrib()
      - define meaning of specific attribute, data types etc.
      - attribute on slot (position) 0 ≈ vertex [xyz] position
    glVertexAttribPointer()
      - array of attributes; vertices and others (interleaved)
    glEnableVertexAttribArray()
      - enable usage of the attribute at specified slot

VAO – direct coordinates

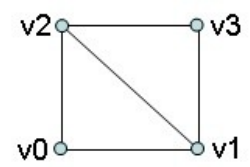
- Only vertices as glm::vec3 (VAO pointer slot = 0)

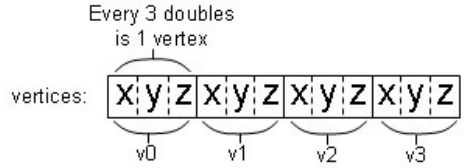
```
    //existing data
    std::vector<glm::vec3> vertices = { };

    //GL names for Array and Buffers Objects
    GLuint VAO, VBO;

    // Generate the VAO and VBO
    glGenVertexArrays(1, &VAO);
    glGenBuffers(1, &VBO);
    // Bind VAO (set as the current)
    glBindVertexArray(VAO);
    // Bind the VBO, set type as GL_ARRAY_BUFFER
    glBindBuffer(GL_ARRAY_BUFFER, VBO);
    // Fill-in data into the VBO
    glBufferData(GL_ARRAY_BUFFER, vertices.size() * sizeof(glm::vec3), vertices.data(), GL_STATIC_DRAW);
    // Set Vertex Attribute to explain OpenGL how to interpret the VBO
    GLint attrib_location = glGetAttribLocation(shader_prog_ID, "attributePosition"); //name in shader src
    glVertexAttribPointer(attrib_location, 3, GL_FLOAT, GL_FALSE, sizeof(glm::vec3),
reinterpret_cast<void*>(0));
    // Enable the Vertex Attribute for position
    glEnableVertexAttribArray(attrib_location);
    // Bind VBO and VAO to 0 to prevent unintended modification of VAO,VBO
    glBindBuffer(GL_ARRAY_BUFFER, 0);
    glBindVertexArray(0);

    // USE
    glUseProgram(shaderProgram);
    glBindVertexArray(VAO);

    glDrawArrays(GL_TRIANGLES, 0, vertices.size());
```

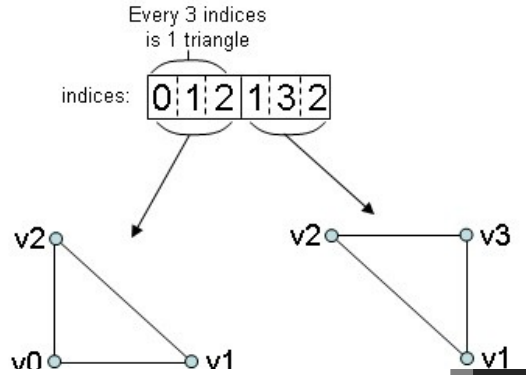




VAO
indirect vertex access





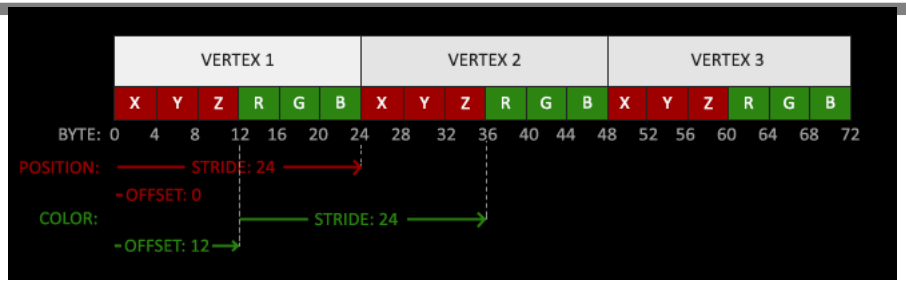



```
    //existing data
    std::vector<glm::vec3> vertices = { };
    std::vector<GLuint> indices = { };

    //GL names for Array and Buffers Objects
    GLuint VAO, VBO, EBO;

    // Generate the VAO and VBO
    glGenVertexArrays(1, &VAO);
    glGenBuffers(1, &VBO);
    glGenBuffers(1, &EBO);
    // Bind VAO (set as the current)
    glBindVertexArray(VAO);
    // Bind the VBO, set type as GL_ARRAY_BUFFER
    glBindBuffer(GL_ARRAY_BUFFER, VBO);
    // Fill-in data into the VBO
    glBufferData(GL_ARRAY_BUFFER, vertices.size() * sizeof(vertex), vertices.data(), GL_STATIC_DRAW);
    // Bind EBO, set type GL_ELEMENT_ARRAY_BUFFER
    glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, EBO);
    // Fill-in data into the EBO
    glBufferData(GL_ELEMENT_ARRAY_BUFFER, indices.size() * sizeof(GLuint), indices.data(), GL_STATIC_DRAW);
    // Set Vertex Attribute to explain OpenGL how to interpret the VBO
    GLint attrib_location = glGetAttribLocation(shader_prog_ID, "attributePosition"); //name in shader src
    glVertexAttribPointer(attrib_location, 3, GL_FLOAT, GL_FALSE, sizeof(glm::vec3),
reinterpret_cast<void*>(0));
    // Enable the Vertex Attribute for position
    glEnableVertexAttribArray(attrib_location);
    // Bind VBO and VAO to 0 to prevent unintended modification of VAO,VBO
    glBindBuffer(GL_ARRAY_BUFFER, 0);
    glBindVertexArray(0);
    glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0);

    // USE
    glUseProgram(shaderProgram);
    glBindVertexArray(VAO);

    glDrawElements(GL_TRIANGLES, indices.size(), GL_UNSIGNED_INT, 0);
```

VAO – additional vertex attributes (colors, normals, etc.)

```
	//existing data
	struct my_vertex {
		glm::vec3 position;  // Vertex
		glm::vec3 normal;    // Normal
		glm::vec2 texcoord;  // Texcoord0
	};
	std::vector<my_vertex> vertices = { };
	…
	// Set Vertex Attribute to explain OpenGL how to interpret the VBO
	GLint attrib_location;
	attrib_location = glGetAttribLocation(shader_prog_ID, "aPos"); //name in shader src
	glVertexAttribPointer(attrib_location, 3, GL_FLOAT, GL_FALSE, sizeof(my_vertex), reinterpret_cast<void*>(0 + offsetof(my_vertex,
position)));
	// Enable the Vertex Attribute for position
	glEnableVertexAttribArray(attrib_location);

	// Set end enable Vertex Attribute for Normal
	attrib_location = glGetAttribLocation(shader_prog_ID, "aNormal"); //name in shader src
	glVertexAttribPointer(attrib_location, 3, GL_FLOAT, GL_FALSE, sizeof(my_vertex), reinterpret_cast<void*>(0 + offsetof(my_vertex, normal)));
	glEnableVertexAttribArray(attrib_location);

	// Set end enable Vertex Attribute forTexture Coordinates
	attrib_location = glGetAttribLocation(shader_prog_ID, "aTex"); //name in shader src
	glVertexAttribPointer(attrib_location, 2, GL_FLOAT, GL_FALSE, sizeof(my_vertex), reinterpret_cast<void*>(0 + offsetof(my_vertex,
texcoord)));
	glEnableVertexAttribArray(attrib_location);
	…
```

```
#version 430 core
layout (location = 0) in vec3 aPos;    // Positions/Coordinates
layout (location = 1) in vec3 aNormal; // Normals
layout (location = 2) in vec2 aTex;    // Texture Coordinates

uniform mat4 uProj_m,uV_m,uM_m;

out VS_OUT {
	vec3 color; // Outputs color for FS
	out vec2 texCoord; // Outputs texture coordinates for FS
} vs_out;

void main() {
	// Outputs coordinates of all vertices
	gl_Position = uProj_m * uV_m * uM_m * vec4(aPos,1.0f);

	// Assigns the colors somehow
	vs_out.color = vec3(1.0); //white

	// Pass the texture coordinates to "texCoord" for FS
	vs_out.texCoord = aTex;
}
```



Single textured triangle: Core profile

```
        //existing data
        struct my_vertex {
                glm::vec3 position;  // Vertex
                glm::vec2 texcoord;  // Texcoord0
        };
        std::vector<my_vertex> vertices = {
                        { {200,50,0}, {0,0} },
                        { {50,250,0}, {0,1} },
                        { {350,250,0}, {1,1} } };
        std::vector<GLuint> indices = {0,1,2};
//============================================================================
        //GL names for Array and Buffers Objects
        GLuint VAO, VBO, EBO;

        // Generate the VAO and VBO
        glGenVertexArrays(1, &VAO);
        glGenBuffers(1, &VBO);
        glGenBuffers(1, &EBO);
        // Bind VAO (set as the current)
        glBindVertexArray(VAO);
        // Bind the VBO, set type as GL_ARRAY_BUFFER
        glBindBuffer(GL_ARRAY_BUFFER, VBO);
        // Fill-in data into the VBO
        glBufferData(GL_ARRAY_BUFFER, vertices.size() * sizeof(vertex),
                vertices.data(), GL_STATIC_DRAW);
        // Bind EBO, set type GL_ELEMENT_ARRAY_BUFFER
        glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, EBO);
        // Fill-in data into the EBO
        glBufferData(GL_ELEMENT_ARRAY_BUFFER, indices.size() * sizeof(GLuint),
                indices.data(), GL_STATIC_DRAW);
        // Set Vertex Attribute to explain OpenGL how to interpret the VBO
        GLint attrib_location;
        attrib_location = glGetAttribLocation(shader_prog_ID, "aPos");
        glVertexAttribPointer(attrib_location, 3, GL_FLOAT, GL_FALSE, sizeof(vertex),
                                (void*)(0 + offsetof(vertex, position)));
        // Enable the Vertex Attribute 0 = position
        glEnableVertexAttribArray(attrib_location);
        // Set end enable Vertex Attribute 1 = Texture Coordinates
        attrib_location = glGetAttribLocation(shader_prog_ID, "aTex");
        glVertexAttribPointer(attrib_location, 2, GL_FLOAT, GL_FALSE, sizeof(my_vertex),
                        (void*)(0 + offsetof(my_vertex, texcoord)));
        glEnableVertexAttribArray(attrib_location);

        // Bind VBO and VAO to 0 to prevent unintended modification
        glBindBuffer(GL_ARRAY_BUFFER, 0);
        glBindVertexArray(0);
        glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0);
//============================================================================
    // create and use shaders
    GLuint VS_h, FS_h, prog_h;
    VS_h = glCreateShader(GL_VERTEX_SHADER);
    FS_h = glCreateShader(GL_FRAGMENT_SHADER);
    glShaderSource(VS_h, 1, &VS_string, NULL);
    glShaderSource(FS_h, 1, &FS_string, NULL);
    glCompileShader(VS_h);
    glCompileShader(FS_h);
    prog_h = glCreateProgram();
    glAttachShader(prog_h, VS_h);
    glAttachShader(prog_h, FS_h);
    glLinkProgram(prog_h);
    glUseProgram(prog_h);
//============================================================================
    // USE buffers
    glBindVertexArray(VAO);

   glDrawElements(GL_TRIANGLES, indices.size(), GL_UNSIGNED_INT, 0);
```

```
#version 430 core
layout (location = 0) in vec3 aPos; // Positions/Coordinates
layout (location = 1) in vec2 aTex; // Texture Coordinates

uniform mat4 uProj_m,uV_m,uM_m;

out VS_OUT {
       vec3 color; // Outputs color for FS
       vec2 texCoord; // Outputs texture coordinates for FS
} vs_out;

void main() {
       // Outputs coordinates of all vertices
       gl_Position = uProj_m * uV_m * uM_m * vec4(aPos,1.0f);

       // Assigns the colors somehow
       vs_out.color = vec3(1.0); //white

       // Pass the texture coordinates to "texCoord" for FS
       vs_out.texCoord = aTex;
}
```

```
#version 430 core
in VS_OUT {
       vec3 color; // color for FS
       vec2 texCoord; // texture coordinates for FS
} fs_in;

uniform sampler2D tex0; // texture unit from C++

out vec4  FragColor; // Final output

void main() {

       FragColor = fs_in.color * texture(tex0, fs_in.texcoord);
}
```