Vertex Array Objects (VAOs)

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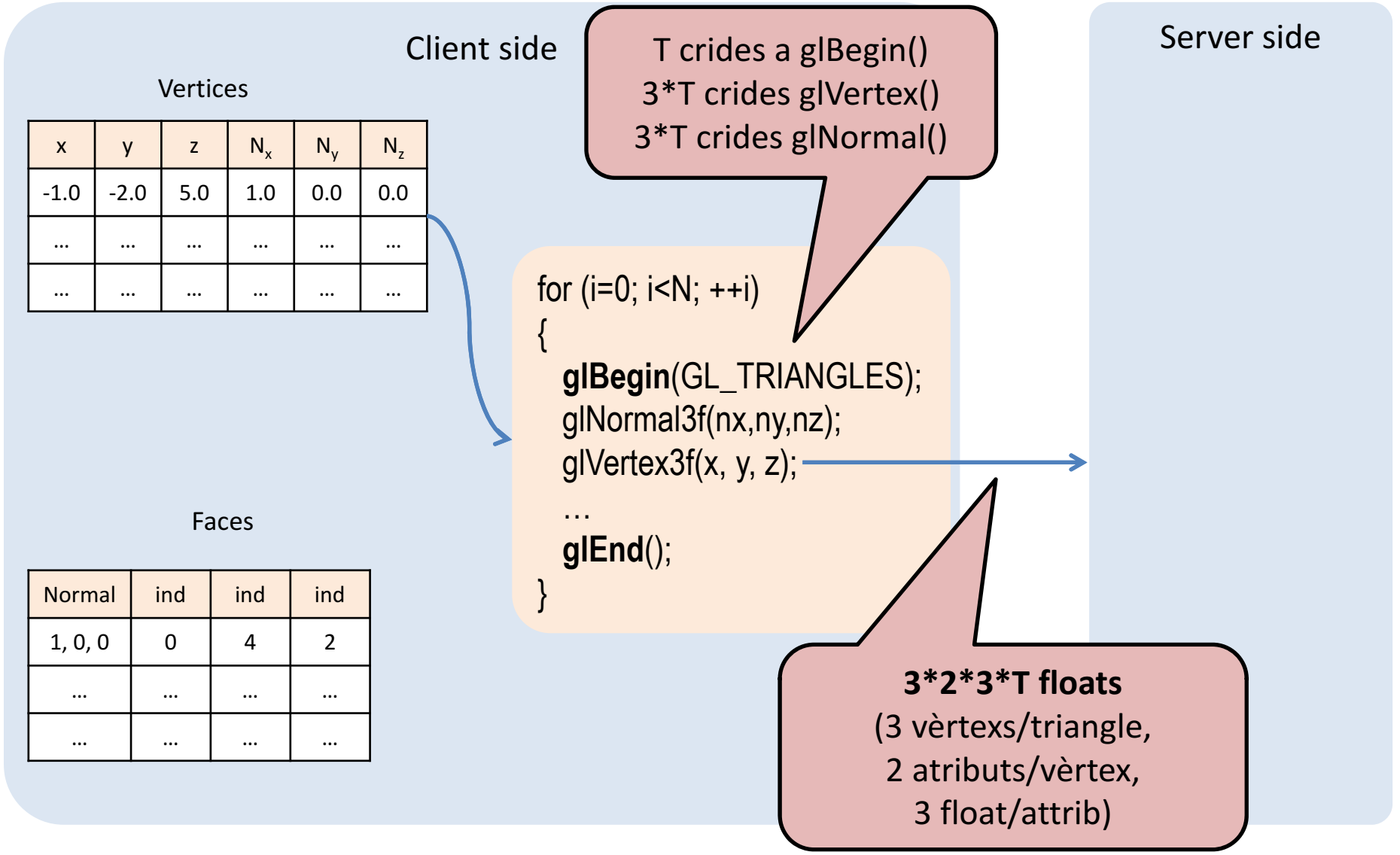
Formes de pintar geometria

- Mode immediat (glBegin,glEnd) (Compatibility)
- Usant Vertex Arrays (VAs) (Compatibility, Core)
- Usant Vertex Array Object (VAOs) (Compatibility, Core)

Mode immediat

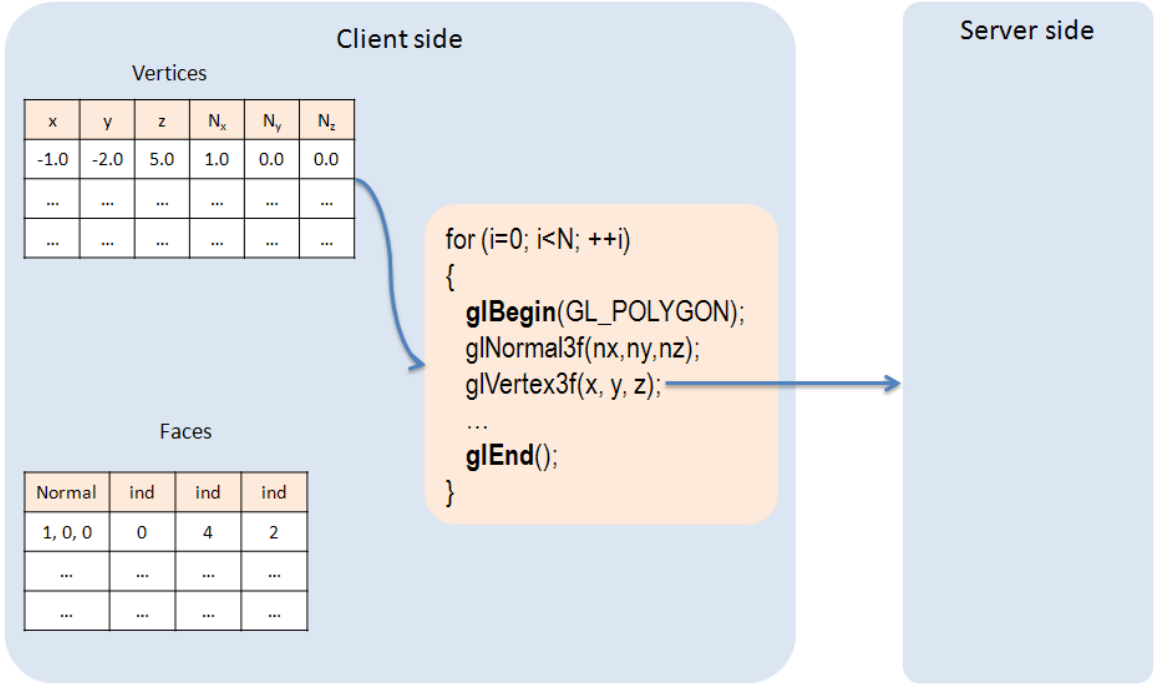
```
for (i=0; i<T; ++i) {
    glBegin(GL_TRIANGLES);
    glNormal3f(…);
    glVertex3f(…);

    glNormal3f(…);
    glVertex3f(…);

    glNormal3f(…);
    glVertex3f(…);
    glEnd();
}
```

Mode immediat



Mode immediat

- Senzill, fàcil de depurar, flexible…
- Moltes crides a funcions
- Cal transferir totes les dades cada frame

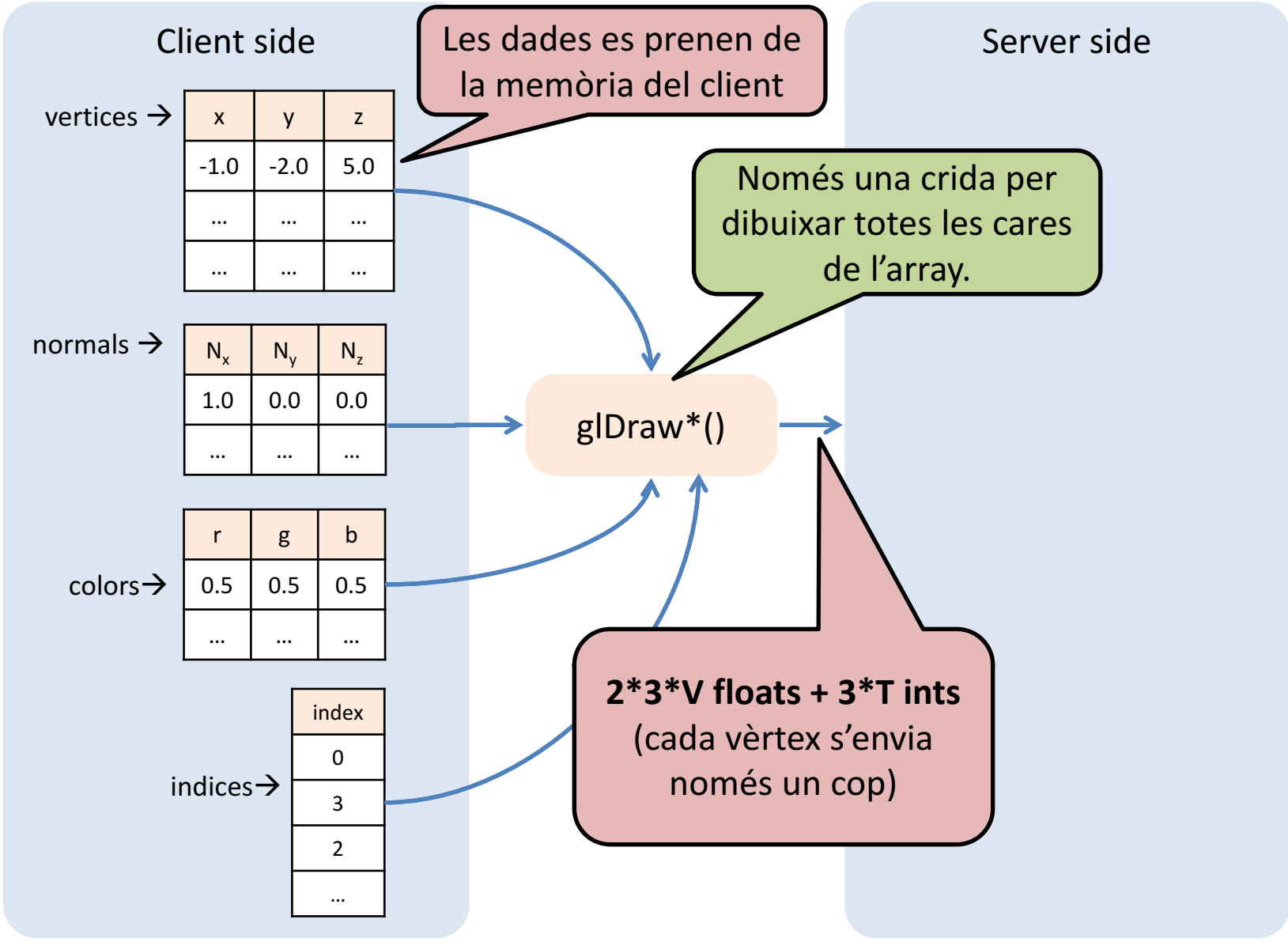


Vertex Arrays

Objectius:

- Reduir crides a OpenGL
- Enviar un cop cada vèrtex

Vertex Arrays



Vertex Arrays

glDrawElements(GL_TRIANGLES, 36, GL_UNSIGNED_INT, indices)

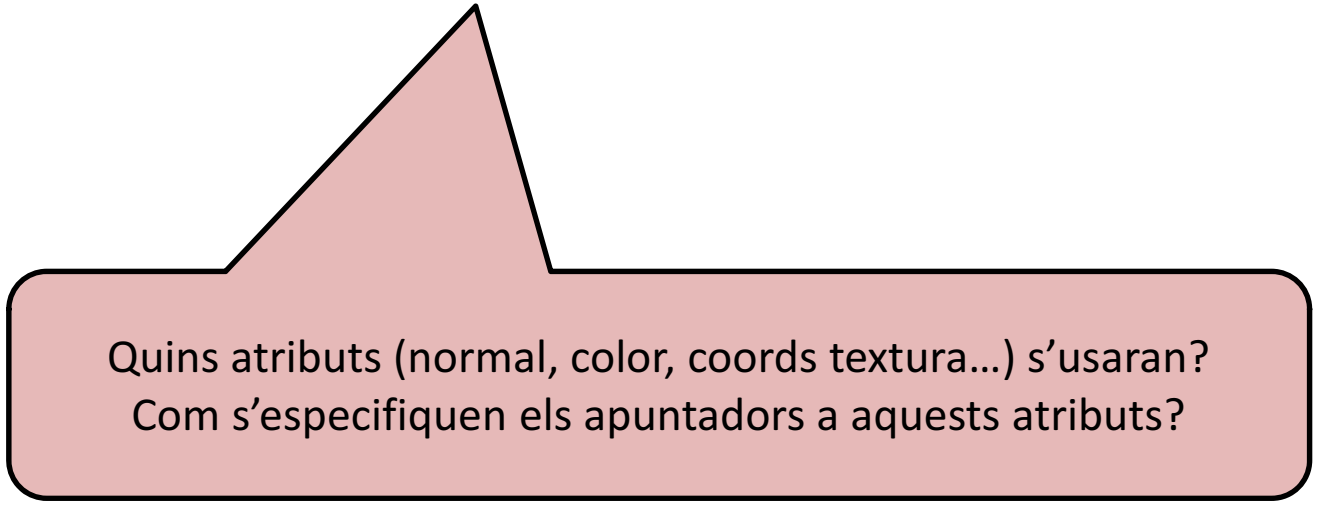
❶ ❷ ❸ ❹

❶ És la primitiva: GL_TRIANGLES, GL_QUADS ...

❷ És el número d'índexos a l'array (ex. 12 triangles → 12*3=36)

❸ És el tipus dels índexs (normalment GL_UNSIGNED_INT)

❹ És l'apuntador a l'array amb els índexs (que haurem definit previament)



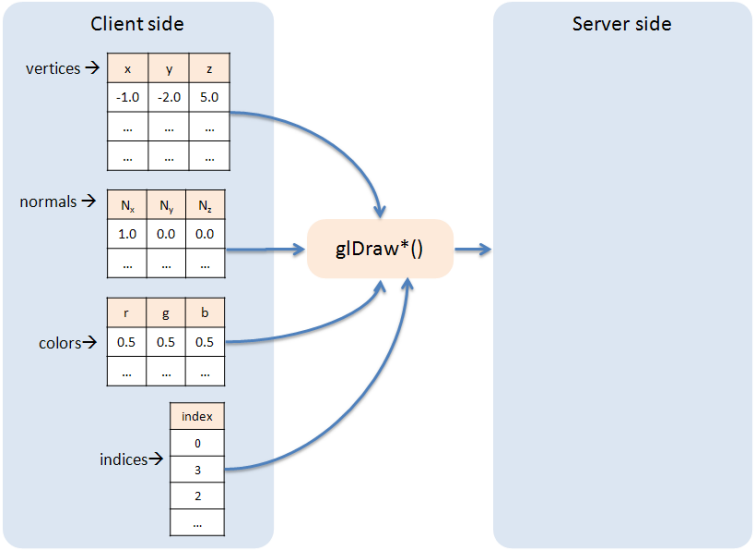
Vertex Arrays

```
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0,
(GLvoid*)verts);
glEnableVertexAttribArray(0);
```

void **glVertexAttribPointer**(
  GLuint index, // VS: **layout (location = 0) in vec3 vertex;**
  GLint size, // Num de coordenades (1,2,3,4)
  GLenum type, // Tipus de cada coordenada: GL_FLOAT …
  GLboolean normalized, // Per convertira valors a [0,1]
  GLsizei stride, // Normalment 0 (un array per cada atribut)
  const GLvoid* pointer); // Apuntador a les dades

Vertex Arrays - resum

- Una única crida a funció (per model 3D)
- Els vèrtexs s'envien un cop
- Menys flexible que el mode immediat
- Encara cal transferir moltes dades cada frame



Vertex buffer object

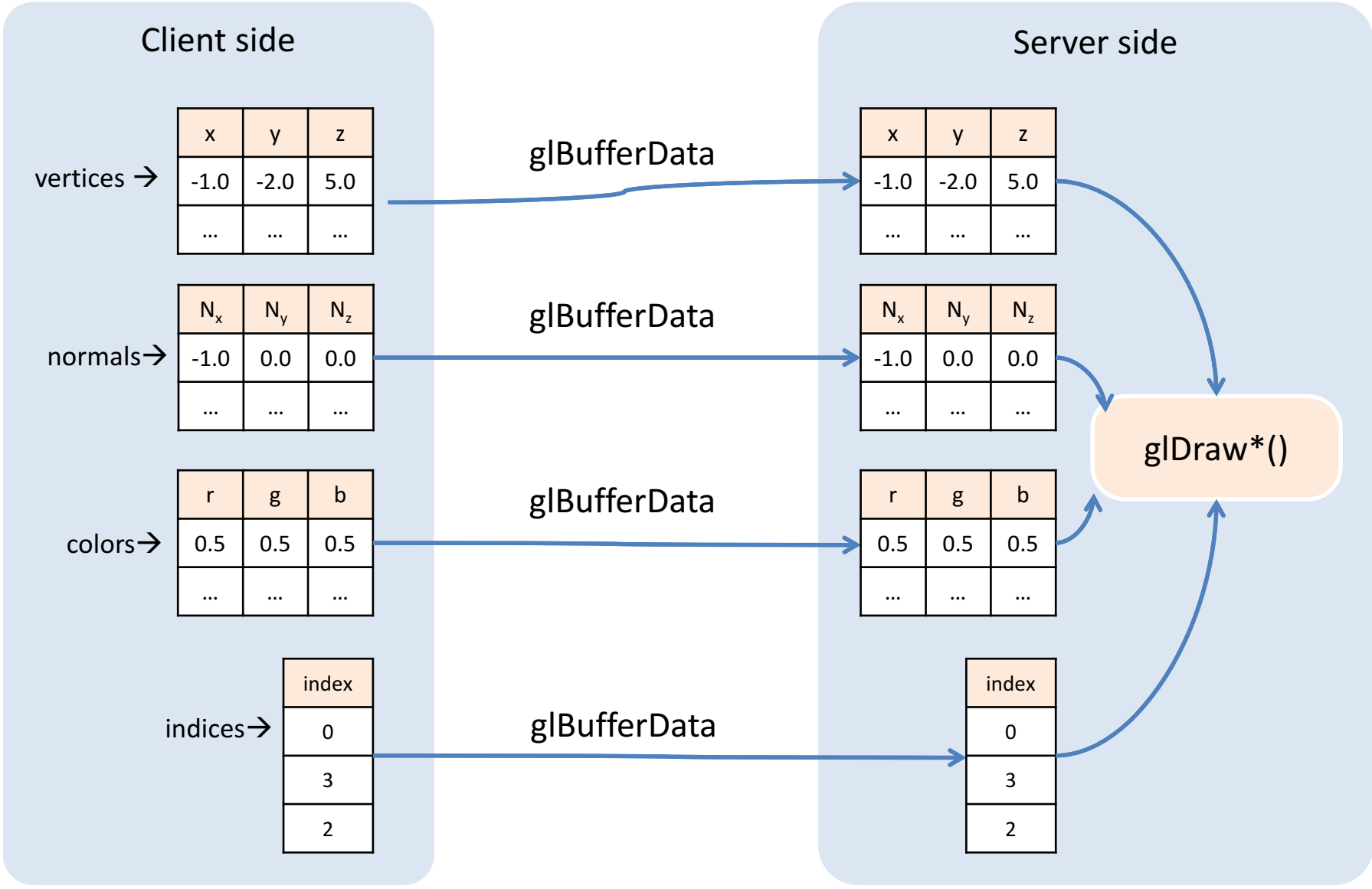
Objectiu:

- Evitar transferir les dades cada frame

Idea:

- Emmagatzemar les dades del VA al servidor!

Vertex buffer object



EXEMPLE 1 – USANT INDEXOS

Setup 1/3

```
// Step 1: Create and fill STL vectors(coords, normals…)
vector<float> vertices;   // (x,y,z)
vector<float> normals;    // (nx,ny,nz)
vector<float> colors;     // (r,g,b)
vector<float> texCoords;  // (s,t)
vector<unsigned int> indices; //i0,i1,i2, i3,i4,i5...
for(...) {
  vertices.push_back(x);
  vertices.push_back(y);
  vertices.push_back(z);
for(...) {
  indices.push_back(index);
```

Setup 2/3

```
// Step 2: Create VAO & empty VBOs
GLuint VAO;
g.glGenVertexArrays(1,&VAO);

GLuint coordBufferID;
g.glGenBuffers(1, &coordBufferID);

GLuint normalBufferID;
g.glGenBuffers(1, &normalBufferID);
…
GLuint indexBufferID;
g.glGenBuffers(1, &indexBufferID);
```

Setup 3/3

```
// Step 3: Define VBO data (coords,normals,indices)
g.glBindVertexArray(VAO);
 g.glBindBuffer(GL_ARRAY_BUFFER, coordBufferID);
 g.glBufferData(GL_ARRAY_BUFFER, sizeof(float)*vertices.size(), &vertices[0],
   GL_STATIC_DRAW);
 g.glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
 g.glEnableVertexAttribArray(0);

 g.glBindBuffer(GL_ARRAY_BUFFER, normalBufferID);
 g.glBufferData(GL_ARRAY_BUFFER, sizeof(float)*normals.size(), &normals[0],
   GL_STATIC_DRAW);
 g.glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 0, 0);
 g.glEnableVertexAttribArray(1);
 ...
 g.glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, indexBuffersID);
 g.glBufferData(GL_ELEMENT_ARRAY_BUFFER,
   sizeof(int)*indices.size(), &indices[0], GL_STATIC_DRAW);

g.glBindVertexArray(0);
```

Draw (amb índexos)

```
// Draw a single instance of the 3D model
g.glBindVertexArray(VAO);
g.glDrawElements(GL_TRIANGLES, numIndices, GL_UNSIGNED_INT, (GLvoid*)0);
//numIndices=indices.size()
g.glBindVertexArray(0);
```

```
// Draw multiple instances of the same 3D model
g.glBindVertexArray(VAO);
g.glDrawElementsInstanced(GL_TRIANGLES, numIndices, GL_UNSIGNED_INT,
(GLvoid*)0, numInstances);
g.glBindVertexArray(0);
```

VS: int gl_InstanceID → instance number (0...numInstances-1)

Clean up

```
// Clean up
g.glDeleteBuffers(1, &coordBufferID);
g.glDeleteBuffers(1, &normalBufferID);
...
g.glDeleteBuffers(1, &indexBufferID);

g.glDeleteVertexArrays(1, &VAO);
```

EXEMPLE 2 – SENSE USAR INDEXOS

Setup 1/3

```
// Step 1: Create and fill STL vectors(coords, normals…)
vector<float> vertices;   // (x,y,z)
vector<float> normals;    // (nx,ny,nz)
vector<float> colors;     // (r,g,b)
vector<float> texCoords;  // (s,t)
vector<unsigned int> indices; //i0,i1,i2, i3,i4,i5...
for(...) {
  vertices.push_back(x); // vèrtexs duplicats!
  vertices.push_back(y);
  vertices.push_back(z);
~~for(...) {~~
~~  indices.push_back(index);~~
```

Setup 2/3

```
// Step 2: Create VAO & empty VBOs
GLuint VAO;
g.glGenVertexArrays(1,&VAO);

GLuint coordBufferID;
g.glGenBuffers(1, &coordBufferID);

GLuint normalBufferID;
g.glGenBuffers(1, &normalBufferID);
…
GLuint indexBufferID;
g.glGenBuffers(1, &indexBufferID);
```

Setup 3/3

```
// Step 3: Define VBO data (coords,normals,indices)
g.glBindVertexArray(VAO);
 g.glBindBuffer(GL_ARRAY_BUFFER, coordBufferID);
 g.glBufferData(GL_ARRAY_BUFFER, sizeof(float)*vertices.size(), &vertices[0],
   GL_STATIC_DRAW);
 g.glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 0, 0);
 g.glEnableVertexAttribArray(0);

 g.glBindBuffer(GL_ARRAY_BUFFER, normalBufferID);
 g.glBufferData(GL_ARRAY_BUFFER, sizeof(float)*normals.size(), &normals[0],
   GL_STATIC_DRAW);
 g.glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 0, 0);
 g.glEnableVertexAttribArray(1);
 ...
 g.glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, indexBuffersID);
 g.glBufferData(GL_ELEMENT_ARRAY_BUFFER,
   sizeof(int)*indices.size(), &indices[0], GL_STATIC_DRAW);

g.glBindVertexArray(0);
```

Draw (sense índexos)

```
// Draw a single instance of the 3D model
g.glBindVertexArray(VAO);
g.glDrawArrays(GL_TRIANGLES, 0, numVertices);
g.glBindVertexArray(0);
```

```
// Draw multiple instances of the same 3D model
g.glBindVertexArray(VAO);
g.glDrawArraysInstanced(GL_TRIANGLES, 0, numVertices, numInstances);
g.glBindVertexArray(0);
```

VS: int gl_InstanceID → instance number (0...numInstances-1)

Clean up

```
// Clean up
g.glDeleteBuffers(1, &coordBufferID);
g.glDeleteBuffers(1, &normalBufferID);
...
g.glDeleteBuffers(1, &indexBufferID);

g.glDeleteVertexArrays(1, &VAO);
```

Vertex Buffer Objects - resum

- Una única crida a funció
- Els vèrtexs s'envien (i processen) un cop (*)
- Les dades es transfereixen al servidor
- Menys flexible que el mode immediat