Vertex Arrays and Vertex Buffer Objects

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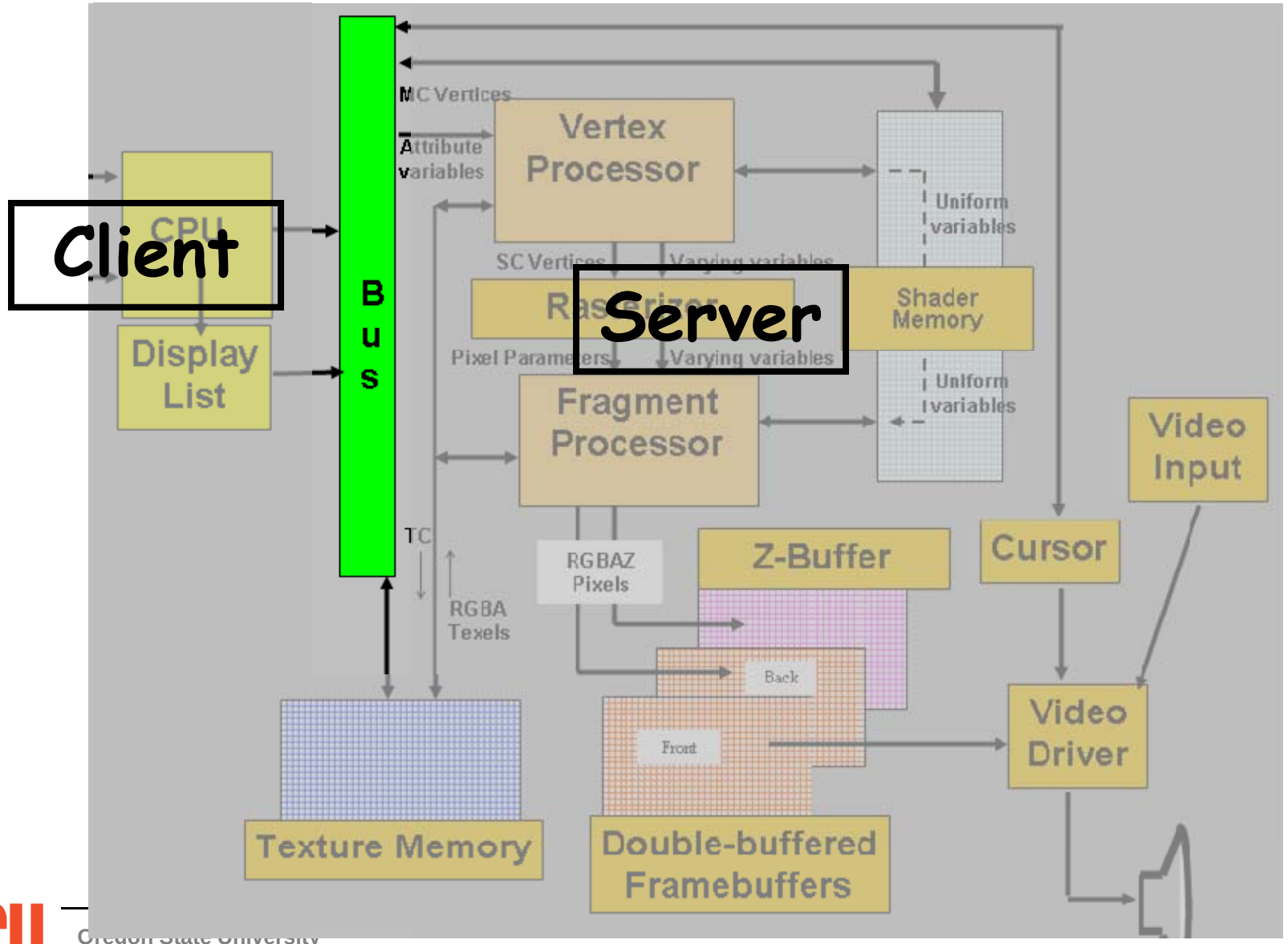
The OpenGL Client-Server Model

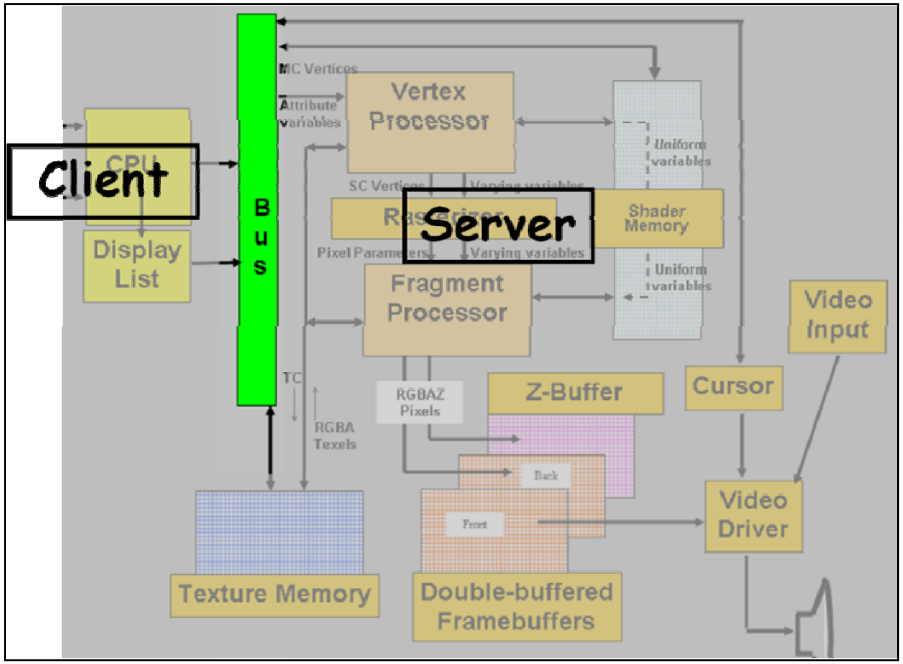


The Difference Between Vertex Arrays and Vertex Buffer Objects

• Both vertex arrays and vertex buffers do the same thing, so functionally they are the same.

• ***Vertex Arrays*** live on the host (the “client”).

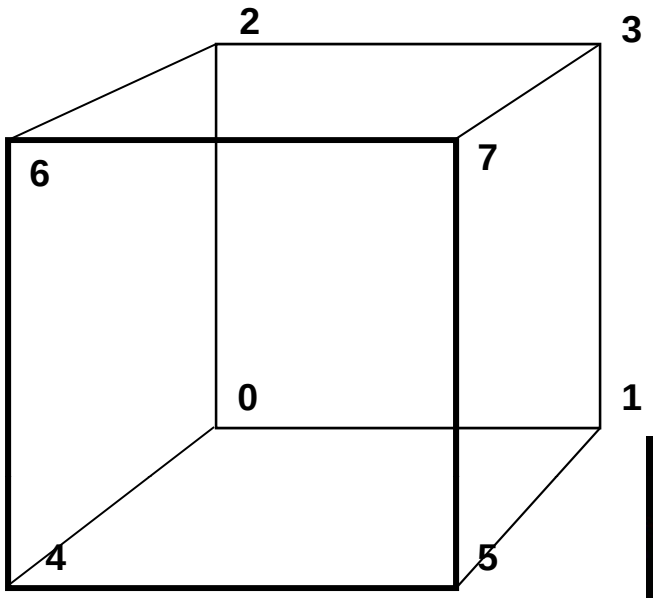
• ***Vertex Buffers*** live on the graphics card (the “server).

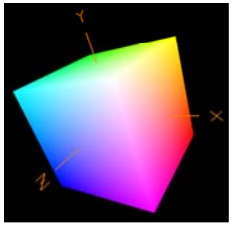


Vertex Arrays: The Big Idea

- Store vertex coordinates and vertex attributes in arrays on the host (client).
- Every time you want to draw, transmit the arrays to the graphics card (server), along with indices that tell what vertex numbers need to be connected.
- This way, each vertex only needs to be transformed *once*.
- It also results in fewer overall function calls (to *glVertex3f( ),* for example).

Vertex Arrays: Cube Example





```
GLfloat CubeVertices[ ][3] =
{
        { -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 CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
GLuint CubeIndices[ ][4] =
{
        { 0, 2, 3, 1 },
        { 4, 5, 7, 6 },
        { 1, 3, 7, 5 },
        { 0, 4, 6, 2 },
        { 2, 6, 7, 3 },
        { 0, 1, 5, 4 }
};
```

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Vertex Arrays: Step #1 – Fill the Arrays

```
GLfloat  Vertices[  ][3] =
{
        { 1., 2., 3. },
        { 4., 5., 6. },
        . . .
};
```

Vertex Arrays: Step #2 – Activate the Array Types That You Will Use

glEnableClientState(type)

where *type* can be any of:

GL_VERTEX_ARRAY
GL_COLOR_ARRAY
GL_NORMAL_ARRAY
GL_SECONDARY_COLOR_ARRAY
GL_TEXTURE_COORD_ARRAY

- Call this as many times as you need to enable all the arrays that you will need.
- There are other types, too.
- To deactivate a type, call:

glDisableClientState(type)

Vertex Arrays: Step #3 – Specify the Data

```
glVertexPointer( size, type, stride, array );
glColorPointer( size, type, stride, array );
glNormalPointer( type, stride, array );
glSecondaryColorPointer( size, type, stride, array );
glTexCoordPointer( size, type, stride, array );
```

size is the spatial dimension, and can be: 2, 3, or 4

type can be:

```
GL_SHORT
GL_INT
GL_FLOAT
GL_DOUBLE
```

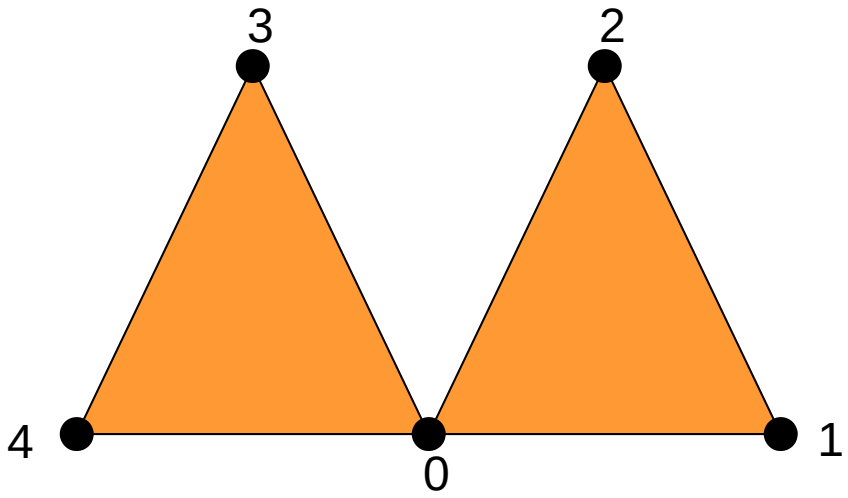
stride is the byte offset between consecutive entries in the array (0 means tightly packed)

array is the name of the corresponding data array

Vertex Arrays: Step #4 – Specify the Connections

List the vertices individually:

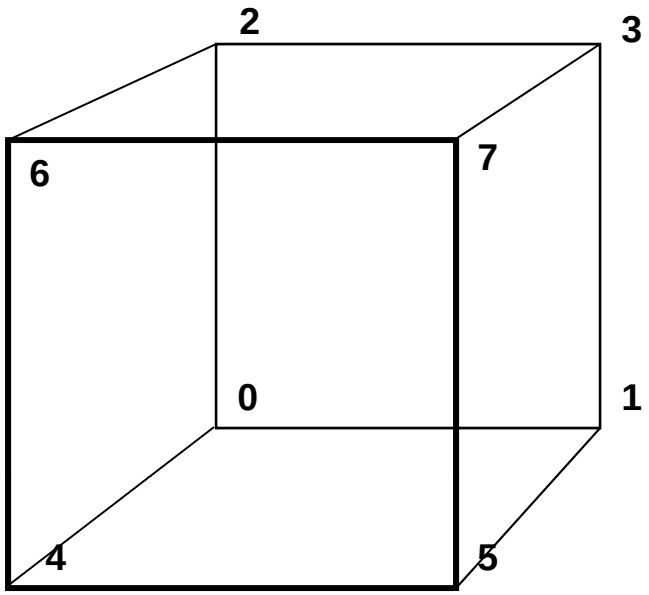
```
glBegin( GL_TRIANGLES );
        glArrayElement( 0 );
        glArrayElement( 1 );
        glArrayElement( 2 );

        glArrayElement( 0 );
        glArrayElement( 3 );
        glArrayElement( 4 );
glEnd( );
```



Or, list the vertices explicitly:

```
GLuint TriIndices[  ][3] =
{
        { 0, 1, 2 },
        { 0, 3, 4 }
};
glDrawElements( GL_TRIANGLES, 6, GL_UNSIGNED_INT, TriIndices );
```

Vertex Arrays: Cube Example




```
GLfloat CubeVertices[ ][3] =
{
        { -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 CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
GLuint CubeIndices[ ][4] =
{
        { 0, 2, 3, 1 },
        { 4, 5, 7, 6 },
        { 1, 3, 7, 5 },
        { 0, 4, 6, 2 },
        { 2, 6, 7, 3 },
        { 0, 1, 5, 4 }
};
```

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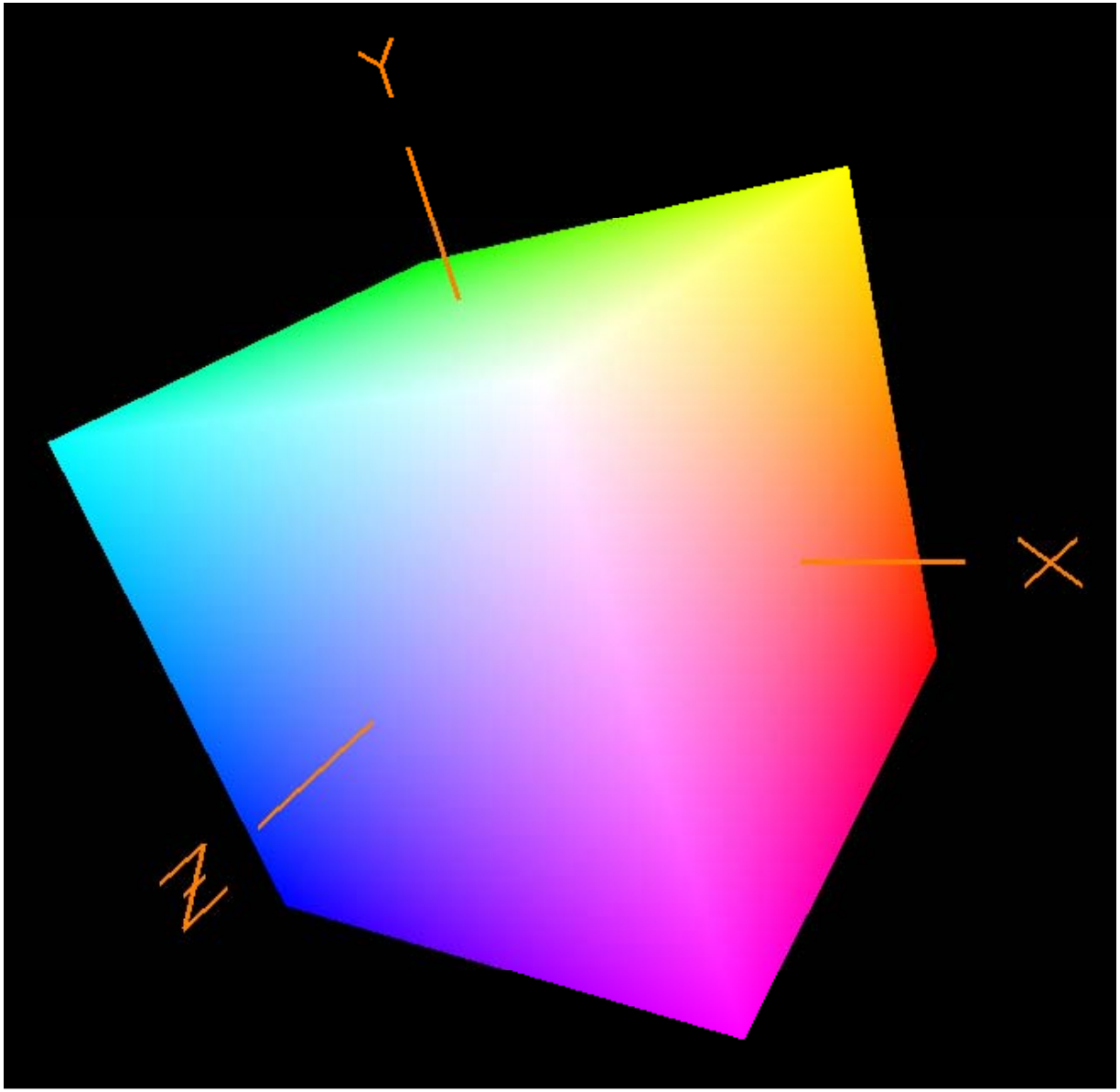
Vertex Arrays: Cube Example



```
glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );
glVertexPointer( 3, GL_FLOAT, 0, CubeVertices );
glColorPointer(   3, GL_FLOAT, 0, CubeColors );
glBegin( GL_QUADS );
        glArrayElement( 0 );
        glArrayElement( 2 );
        glArrayElement( 3 );
        glArrayElement( 1 );
        glArrayElement( 4 );
        glArrayElement( 5 );
        glArrayElement( 7 );
        glArrayElement( 6 );
        glArrayElement( 1 );
        glArrayElement( 3 );
        glArrayElement( 7 );
        glArrayElement( 5 );
        glArrayElement( 0 );
        glArrayElement( 4 );
        glArrayElement( 6 );
        glArrayElement( 2 );
        glArrayElement( 2 );
        glArrayElement( 6 );
        glArrayElement( 7 );
        glArrayElement( 3 );
        glArrayElement( 0 );
        glArrayElement( 1 );
        glArrayElement( 5 );
        glArrayElement( 4 );
glEnd( );
```

Vertex Arrays:
Cube Example – glArrayElement( ) calls

Vertex Arrays:
Cube Example – glDrawElements( ) call

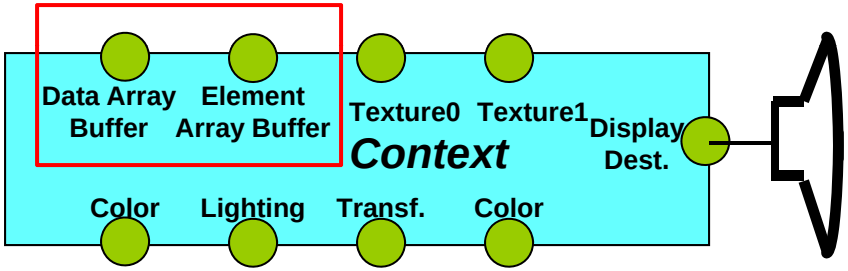
```
glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );

glVertexPointer( 3, GL_FLOAT, 0, CubeVertices );
glColorPointer(  3, GL_FLOAT, 0, CubeColors );

glDrawElements( GL_QUADS, 24, GL_UNSIGNED_INT, CubeIndices );
```

Vertex *Buffers*: The Big Idea

- Store vertex coordinates and vertex attributes in arrays on the ***graphics card*** (server).
- Optionally store the connections on the graphics card too.
- Every time you want to draw, the vertex arrays are already on the graphics card, possibly along with indices that tell what vertex numbers need to be connected. If the indices are not already there, send them.

A Little Background -- the OpenGL *Rendering Context*

The OpenGL Rendering Context contains all the characteristic information necessary to produce an image from geometry. This includes transformations, colors, lighting, textures, where to send the display, etc.



Some of these characteristics have a default value (e.g., lines are white, the display goes to the screen) and some have nothing (e.g., no textures exist)

More Background – What is an OpenGL "Object"?

An OpenGL Object is pretty much the same as a C++, C#, or Java object: it encapsulates a group of data items and allows you to treat them as a single whole. For example, a Vertex Buffer Object *could* be defined in C++ by:

```
class VertexBufferObject
{
        enum dataType;
        void *memStart;
        int memSize;
};
```

Then, you could create any number of Vertex Buffer Object instances, each with its own characteristics encapsulated within it. When you want to make that combination current, you just need to bring in ("bind") that entire object. When you bind an object, all of its information comes with it.

More Background – How do you Create an OpenGL "Object"?

In C++, objects are pointed to by their address.

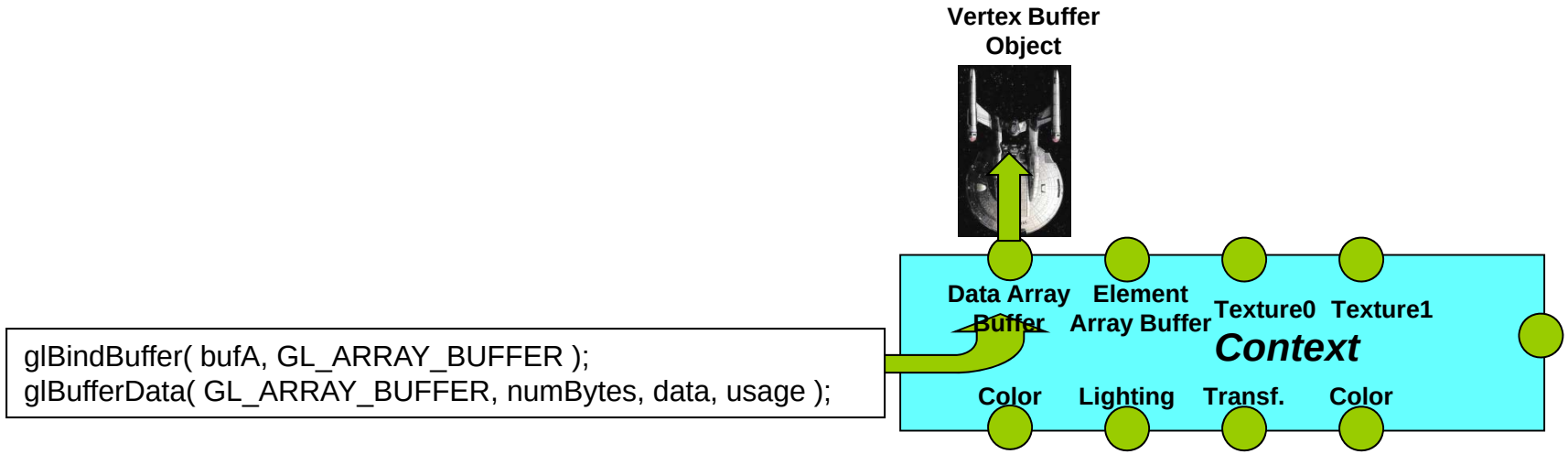
In OpenGL, objects are pointed to by an unsigned integer handle. You can assign a value for this handle yourself (not recommended), or have OpenGL generate one for you that is guaranteed to be unique. For example:

```
GLuint bufA;

glGenBuffers( 1, &bufA );
```

This doesn't actually allocate memory for the buffer object yet, it just acquires a unique handle. To allocate memory, you need to bind this handle to the Context.

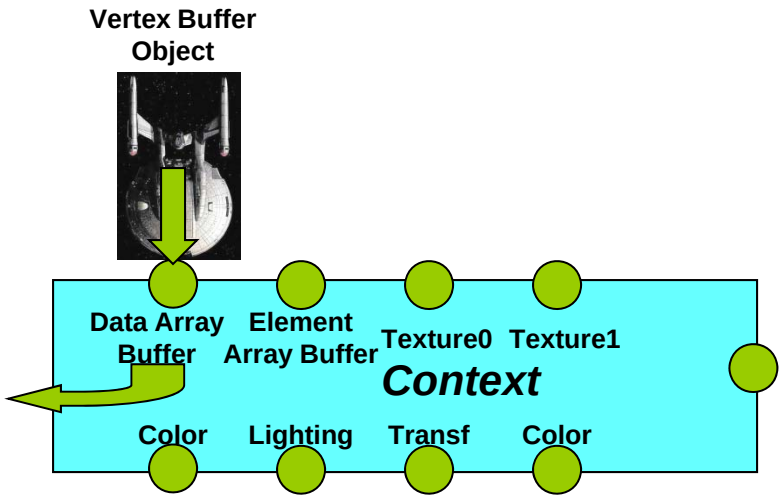
More Background -- “Binding” to the Context

The OpenGL term “binding” refers to “attaching” or “docking” (a metaphor which I find to be more visually pleasing) an OpenGL object to the Context. You can then assign characteristics, and they will “flow” through the Context into the object.



More Background -- “Binding” to the Context

When you want to *use* that Vertex Buffer Object, just bind it again. All of the characteristics will then be active, just as if you had specified them again.




```
glBindBuffer( bufA, GL_ARRAY_BUFFER );
```

Vertex Buffers: Putting Data in the Buffer Object

```
glBufferData( type,  numBytes,  data,  usage );
```

type is the type of buffer object this is:
GL_ARRAY_BUFFER to store floating point vertices, normals, colors, and texture coordinates

GL_ELEMENT_ARRAY_BUFFER to store integer vertex indices to connect for drawing

numBytes is the number of bytes to store in all. Not the number of numbers, but the number of bytes!

data is the memory address of (i.e., pointer to) the data to be transferred to the graphics card. This can be NULL, and the data can be transferred later.

Vertex Buffers: Putting Data in the Buffer Object

```
glBufferData( type,  numbytes,  data,  usage );
```

usage is a hint as to how the data will be used: GL_xxx_yyy

where xxx can be:

STREAM	this buffer will be written lots
STATIC	this buffer will be written seldom and read seldon
DYNAMIC	this buffer will be written often and used often

and yyy can be:

DRAW	this buffer will be used for drawing
READ	this buffer will be copied into
COPY	not a real need for now, but someday…

Vertex Buffers: A Choice of Terminology

The architects of OpenGL had a choice at this point. They could let vertex buffer objects use the same terminology as vertex arrays, or they could invent new terminology.

They decided to re-use the same terminology to make conversion from vertex arrays to vertex buffers that much easier. Don't take the use of the word ***Client*** seriously here!

Vertex Buffers: Step #1 – Fill the Arrays

```
GLfloat  Vertices[  ][3] =
{
        { 1., 2., 3. },
        { 4., 5., 6. },
        . . .
};
```

Vertex Buffers: Step #2 – Create the Buffers and Fill Them

```
glGenBuffers( 1, &bufA );

glBindBuffer( bufA, GL_ARRAY_BUFFER );
glBufferData( GL_ARRAY_BUFFER, 3*sizeof(float)*numVertices, Vertices, GL_DYNAMIC_DRAW );
```

Vertex Buffers: Step #3 – Activate the Array Types That You Will Use

glEnableClientState(type)

where *type* can be any of:

GL_VERTEX_ARRAY
GL_COLOR_ARRAY
GL_NORMAL_ARRAY
GL_SECONDARY_COLOR_ARRAY
GL_TEXTURE_COORD_ARRAY

- Call this as many times as you need to enable all the arrays that you will need.
- There are other types, too.
- To deactivate a type, call:

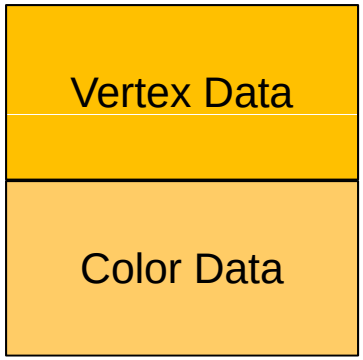
glDisableClientState(type)

Vertex Buffers: Step #4 – To Draw, Bind the Buffers

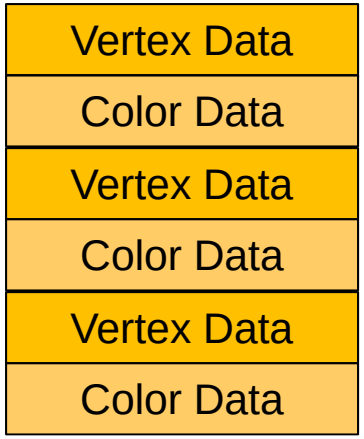
```
glBindBuffer( bufA, GL_ARRAY_BUFFER );
glBindBuffer( bufB, GL_ELEMENT_ARRAY_BUFFER );
```

Vertex Buffers: Step #5 – Specify the Data

```
glVertexPointer( size, type, stride, offset);
glColorPointer( size, type, stride, offset);
glNormalPointer( type, stride, offset);
glSecondaryColorPointer( size, type, stride, offset);
glTexCoordPointer( size, type, stride, offset);
```



vs.



size is the spatial dimension, and can be: 2, 3, or 4

type can be:

```
GL_SHORT
GL_INT
GL_FLOAT
GL_DOUBLE
```

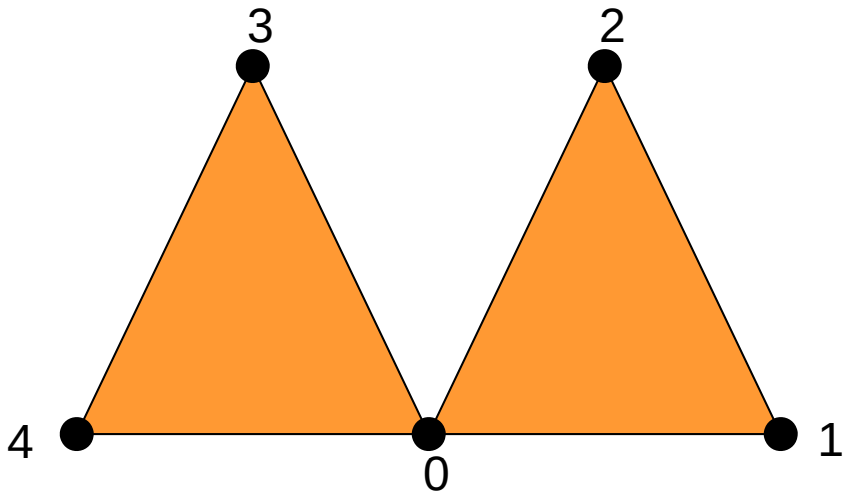
stride is the byte offset between consecutive entries in the array (0 means tightly packed)

offset, the 4th argument, is no longer an array memory location. It is the byte offset from the start of the data array buffer where the first element of this part of the data lives.

Vertex Buffers: Step #6 – Specify the Connections

List the vertices individually:

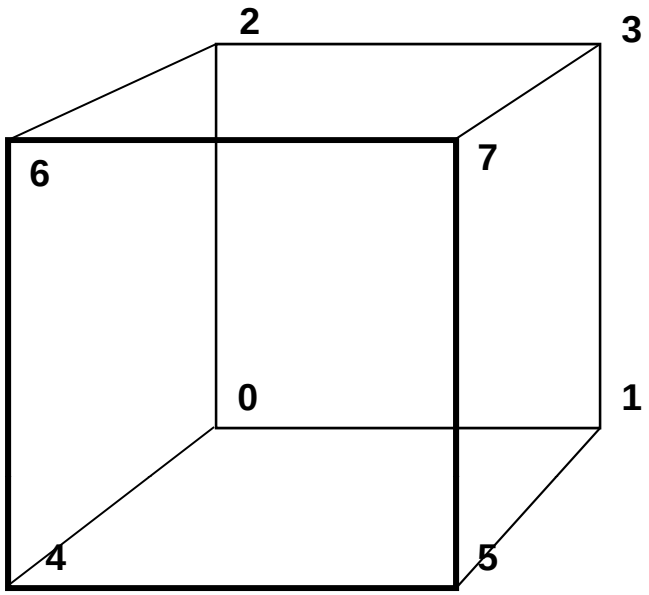
```
glBegin( GL_TRIANGLES );
        glArrayElement( 0 );
        glArrayElement( 1 );
        glArrayElement( 2 );

        glArrayElement( 0 );
        glArrayElement( 3 );
        glArrayElement( 4 );
glEnd( );
```



List the vertices together:

```
GLuint TriIndices[  ][3] =
{
        { 0, 1, 2 },
        { 0, 3, 4 }
};
glDrawElements( GL_TRIANGLES, 6, GL_UNSIGNED_INT, TriIndices );
```

Vertex Buffers: Cube Example




```
static GLfloat CubeVertices[ ][3] =
{
        { -1., -1., -1. },
        {  1., -1., -1. },
        { -1.,  1., -1. },
        {  1.,  1., -1. },
        { -1., -1.,  1. },
        {  1., -1.,  1. },
        { -1.,  1.,  1. },
        {  1.,  1.,  1. }
};
```

```
static GLfloat CubeColors[ ][3] =
{
        { 0., 0., 0. },
        { 1., 0., 0. },
        { 0., 1., 0. },
        { 1., 1., 0. },
        { 0., 0., 1. },
        { 1., 0., 1. },
        { 0., 1., 1. },
        { 1., 1., 1. },
};
```

```
static GLuint CubeIndices[ ][4] =
{
        { 0, 2, 3, 1 },
        { 4, 5, 7, 6 },
        { 1, 3, 7, 5 },
        { 0, 4, 6, 2 },
        { 2, 6, 7, 3 },
        { 0, 1, 5, 4 }
};
```

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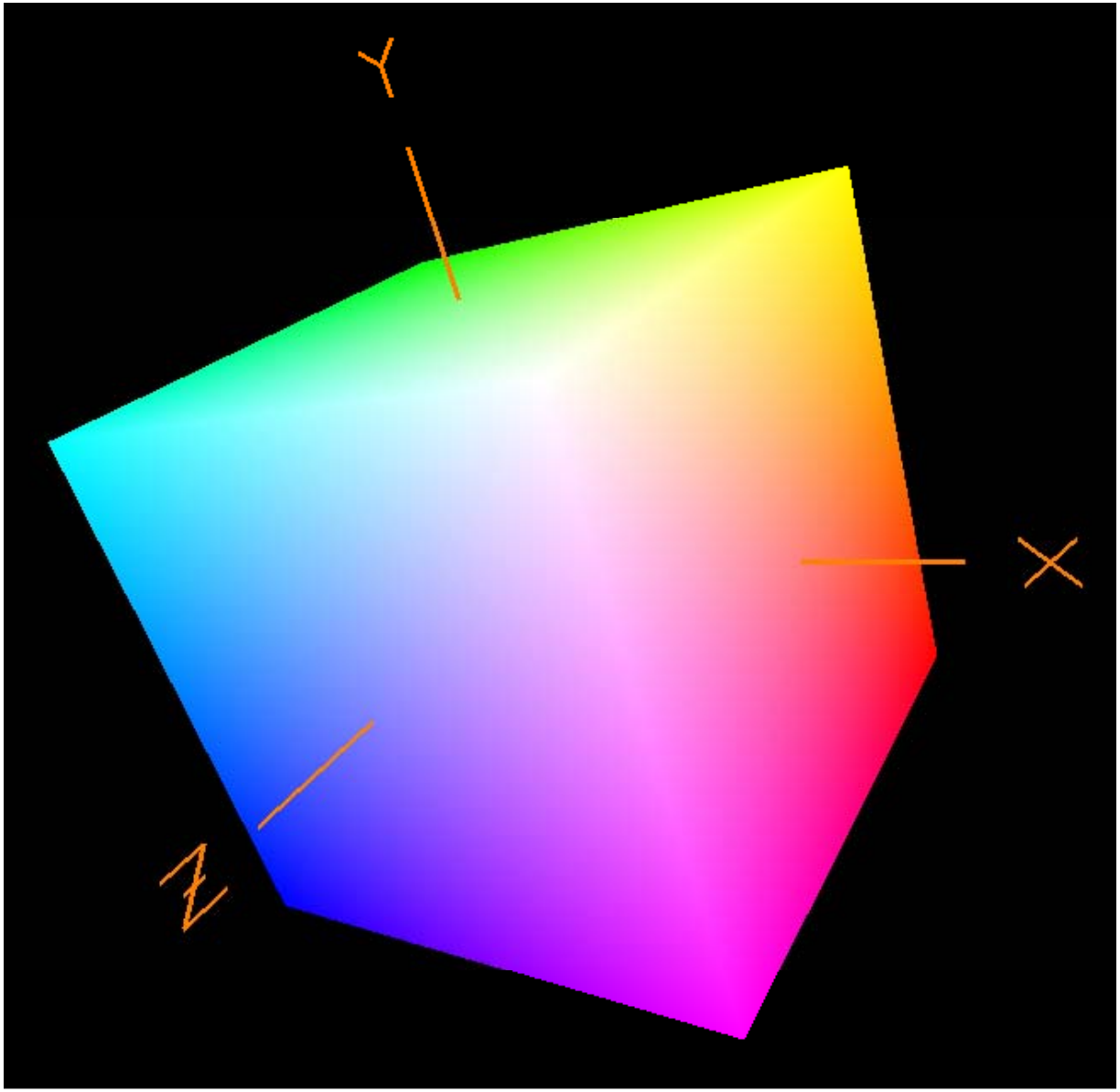
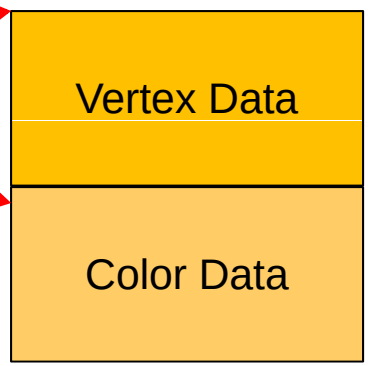
Vertex Buffers: Cube Example



```
glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );
glVertexPointer(  3, GL_FLOAT, 0, (Gluchar*) 0 );
glColorPointer(   3, GL_FLOAT, 0, (Gluchar*) (3*sizeof(float)*numVertices) );
glBegin( GL_QUADS );
        glArrayElement( 0 );
        glArrayElement( 2 );
        glArrayElement( 3 );
        glArrayElement( 1 );
        glArrayElement( 4 );
        glArrayElement( 5 );
        glArrayElement( 7 );
        glArrayElement( 6 );
        glArrayElement( 1 );
        glArrayElement( 3 );
        glArrayElement( 7 );
        glArrayElement( 5 );
        glArrayElement( 0 );
        glArrayElement( 4 );
        glArrayElement( 6 );
        glArrayElement( 2 );
        glArrayElement( 2 );
        glArrayElement( 6 );
        glArrayElement( 7 );
        glArrayElement( 3 );
        glArrayElement( 0 );
        glArrayElement( 1 );
        glArrayElement( 5 );
        glArrayElement( 4 );
glEnd( );
```



Vertex Buffers: Cube Example – glArrayElement( ) calls

Vertex Buffers:
Cube Example – glDrawElements( ) call

```
glEnableClientState( GL_VERTEX_ARRAY );
glEnableClientState( GL_COLOR_ARRAY );

glVertexPointer( 3, GL_FLOAT, 0, (Gluchar*) 0 );
glColorPointer(  3, GL_FLOAT, 0, (Gluchar*) (3*sizeof(float)*numVertices) );

glDrawElements( GL_QUADS, 24, GL_UNSIGNED_INT, (Gluchar*) 0 );
```

Vertex Buffers: Re-writing Data into a Vertex Buffer

```
float * vertexArray = glMapBuffer( GL_ARRAY_BUFFER,  usage );
```

usage is a hint as to how the data will be used:

GL_READ_ONLY	the vertex data will be read from, but not written to
GL_WRITE	the vertex data will be written to
GL_READ_WRITE	the vertex data will be read from and written to

You can now use vertexArray[ ] like any other floating-point array.

When you are done, be sure to call:

```
glUnMapBuffer( GL_ARRAY_BUFFER );
```