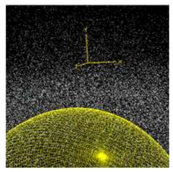
1

OpenCL / OpenGL Vertex Buffer Interoperability: A Particle System Case Study

Also, see the video at:
http://cs.oregonstate.edu/~mjb/cs575/Projects/particles.mp4

Oregon State University
Mike Bailey
mjb@cs.oregonstate.edu



1

OpenCL / OpenGL Vertex Interoperability: The Basic Idea

2

Your C++ program writes initial values into the buffer on the GPU

(x,y,z) Vertex Data in an OpenGL Buffer

OpenCL acquires the buffer

Each OpenCL kernel reads an (x,y,z) value from the buffer

Each OpenCL kernel updates its (x,y,z) value

Each OpenCL kernel writes its (x,y,z) value back to the buffer

OpenCL releases the buffer

OpenGL draws using the (x,y,z) values in the buffer on the GPU

2

Some of the Inner Workings of OpenGL: Feel Free to Detour Right to Slide #24 if You Don't Want to Know This

3

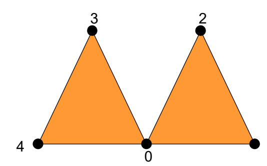
3

In the Beginning of OpenGL …

4

You listed the vertices with separate function calls:

```
glBegin( GL_TRIANGLES );
        glVertex3f( x0, y0, z0 );
        glVertex3f( x1, y1, z1 );
        glVertex3f( x2, y2, z2 );

        glVertex3f( x0, y0, z0 );
        glVertex3f( x3, y3, z3 );
        glVertex3f( x4, y4, z4 );
glEnd( );
```



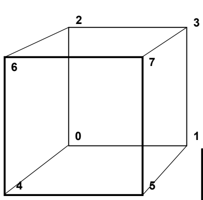
Then someone noticed how inefficient that was, for three reasons:

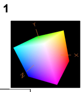
1. **Sending large amounts of small pieces of information is less efficient than sending small amounts of large pieces of information**
2. **The vertex coordinates were being listed in the CPU and were being transferred to the GPU every drawing pass**
3. **Some vertices were listed twice**

4

Here's What OpenGL Has Been Moving To: Vertex Buffer Objects

5





```
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. },
};
```

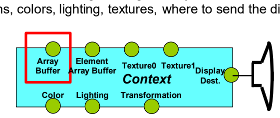
```
GLuint CubeIndices[ ][4] =
{
        { 0, 2, 3, 1 },
        { 4, 5, 7, 6 },
        { 1, 3, 7, 5 },
        { 0, 4, 6, 2 },
        { 2, 6, 7, 3 },
        { 0, 1, 5, 4 }
};
```


5

A Little Background -- the OpenGL *Rendering Context*

6

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.



If we were implementing the OpenGL state as a C++ structure (which we're not), we might do something like this:

```
struct context
{
        float [4]                       Color;
        float [4][4]                    Transformation;
        struct Texture *                Texture0;
        struct DataArrayBuffer *        ArrayBuffer;
        . . .
} Context;
```


6

More Background – How do you create a special OpenGL Array Buffer called a Vertex Buffer Object?

7

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 buf;

glGenBuffers( 1, &buf );
```

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.

Oregon State University Computer Graphics

mjb – March 27, 2021

7

More Background – What is an OpenGL "Object"?

8

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

```
struct  DataArrayBuffer
{
        enum      dataType;
        void *    memStart;
        int       memSize;
};
```

Then, you could create any number of Buffer Object instances, each with its own characteristics encapsulated within it. When you want to make that combination current, you just need to point the ArrayBuffer element of the Context to that entire struct **("bind")**. When you bind an object, all of its information comes with it.

Oregon State University Computer Graphics

mjb – March 27, 2021

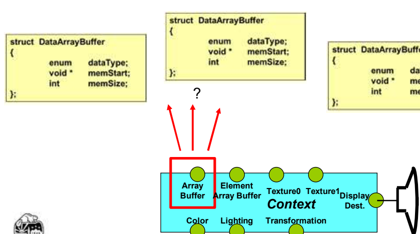
8

A Little Background -- the OpenGL *Rendering Context*

9

It's very fast to re-bind a different vertex buffer. It amounts to just changing a pointer.

```
glBindBuffer( GL_ARRAY_BUFFER, buf );
```



Oregon State University Computer Graphics

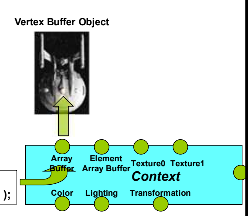
mjb – March 27, 2021

9

More Background -- "Binding" to the Context

10

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.




```
glBindBuffer( GL_ARRAY_BUFFER, buf );
glBufferData( GL_ARRAY_BUFFER, numBytes, data, usage );
```

Think of it as happening this way:

```
Context.ArrayBuffer.memStart = CopyToGpuMemory( data, numBytes );
Context.ArrayBuffer.memSize = numBytes;
```

Oregon State University Computer Graphics

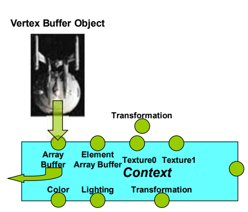
mjb – March 27, 2021

10

More Background -- "Binding" to the Context

11

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( GL_ARRAY_BUFFER, buf );
```

Think of it as happening this way:

```
float *data = Context.ArrayBuffer.memStart;
```

Oregon State University Computer Graphics

mjb – March 27, 2021

11

Vertex Buffers: Putting Data in the Buffer Object

12

```
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

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

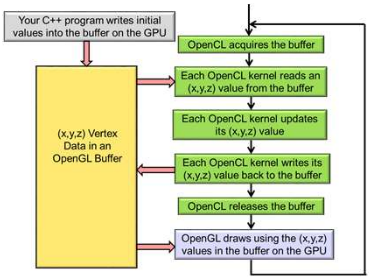
data is the memory address of (i.e., pointer to) the data to be transferred to the graphics card. *This can be NULL, and the data can be transferred later via memory-mapping.*

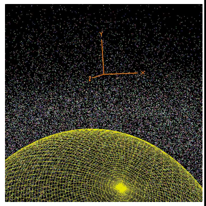
Oregon State University Computer Graphics

mjb – March 27, 2021

12

Preview: We are going to use a Particle System as a Case Study





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 often
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…

GL_STATIC_DRAW is the most common usage

Vertex Buffers: Step #1 – Fill the Arrays


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

int numVertices = sizeof(Vertices)  /  ( 3*sizeof(GLfloat) );
```


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


```
glGenBuffers( 1, &buf );

glBindBuffer( GL_ARRAY_BUFFER, buf );
glBufferData( GL_ARRAY_BUFFER, 3*sizeof(GLfloat)*numVertices, Vertices, GL_STATIC_DRAW );
```


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

glEnableClientState(type)

where *type* can be any of:

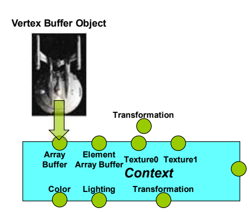
```
GL_VERTEX_ARRAY
GL_COLOR_ARRAY
GL_NORMAL_ARRAY
GL_TEXTURE_COORD_ARRAY
```

- 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, First Bind the Buffers

glBindBuffer(GL_ARRAY_BUFFER, buf);



Vertex Buffers: Step #5 – Specify the Data

19

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

Vertex Data
Color Data

vs.

Vertex Data
Color Data
Vertex Data
Color Data
Vertex Data
Color Data

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)

rel_address, the 4th argument, is the relative byte address from the start of the buffer where the first element of this part of the data lives.

Oregon State University Computer Graphics

mjb – March 27, 2021

19

The Data Types in a vertex buffer object can be stored either as "packed" or "interleaved"

20

```
gl*Pointer( size, type, stride, offset);
```

rel_address, the 4th argument, is the relative byte address from the start of the buffer where the first element of this part of the data lives.

Packed:

```
glVertexPointer( 3, GL_FLOAT, 3*sizeof(GLfloat), 0 );

glColorPointer( 3, GL_FLOAT, 3*sizeof(GLfloat), 3*numVertices*sizeof(GLfloat));
```

stride start

Vertex Data
Color Data

Interleaved:

```
glVertexPointer( 3, GL_FLOAT, 6*sizeof(GLfloat), 0 );

glColorPointer( 3, GL_FLOAT, 6*sizeof(GLfloat), 3*sizeof(GLfloat) );
```

Vertex Data
Color Data
Vertex Data
Color Data
Vertex Data
Color Data

Oregon State University Computer Graphics

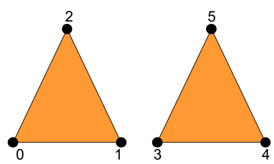
mjb – March 27, 2021

20

Vertex Buffers: Step #6 – Specify the Connections

21

```
GLfloat Vertices[ ][3] =
{
        { x0, y0, z0 },
        { x1, y1, z1 },
        { x2, y2, z2 },
        { x3, y3, z3 },
        { x4, y4, z4 },
        { x5, y5, z5 }
};
```




```
int numVertices = sizeof(Vertices) / ( 3*sizeof(GLfloat) );

glDrawArrays( GL_TRIANGLES, 0, numVertices );
```

Oregon State University Computer Graphics

mjb – March 27, 2021

21

Vertex Buffers: Writing Data Directly into a Vertex Buffer

22

Map the buffer from GPU memory into the memory space of the application:

```
glBindBuffer( buf, GL_ARRAY_BUFFER );
glBufferData( GL_ARRAY_BUFFER, 3*sizeof(float)*numVertices, NULL, GL_STATIC_DRAW );

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

Allocates the bytes, but doesn't deliver any data

usage is an indication how the data will be used:

GL_READ_ONLY	the vertex data will be read from, but not written to
GL_WRITE_ONLY	the vertex data will be written to, but not read from
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 );
```

Oregon State University Computer Graphics

mjb – March 27, 2021

22

We Now Pickup with the OpenCL Stuff

23

Oregon State University Computer Graphics

mjb – March 27, 2021

23

We Now Pickup with the OpenCL Stuff

24

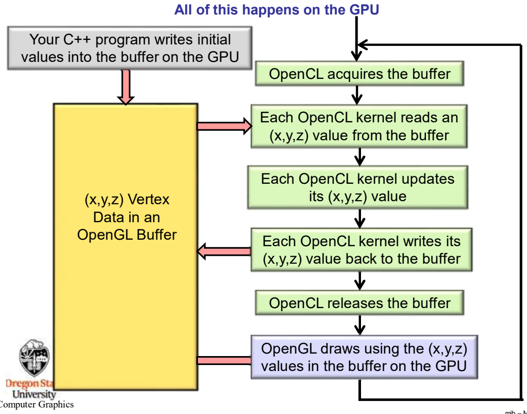
Oregon State University Computer Graphics

mjb – March 27, 2021

24

Either OpenGL or OpenCL can use the Vertex Buffer at a time, but not both: All of this happens on the GPU

25



Oregon State University Computer Graphics

1. Program Header

26

```
#include <stdio.h>
#define _USE_MATH_DEFINES
#include <math.h>
#include <string.h>
#include <stdlib.h>
#include <ctype.h>
#include <omp.h>


#ifdef WIN32
#include <windows.h>
#endif

#ifdef WIN32
#include "glew.h"
#endif

#include <GL/gl.h>
#include <GL/glu.h>
#include "glut.h"
#include "glui.h"

#include "CL/cl.h"
#include "CL/cl_gl.h"
```

Oregon State University Computer Graphics

Structures We Will Use to Fill the Vertex Buffers

27

```
// structs we will need later:

struct xyzw
{
        float x, y, z, w;
};


struct rgba
{
        float r, g, b, a;
};
```

Oregon State University Computer Graphics

OpenCL Global Variables

28

```
size_t  GlobalWorkSize[3] = { NUM_PARTICLES, 1, 1 };
size_t   LocalWorkSize[3] = { LOCAL_SIZE,    1, 1 };

GLuint              hPobj;   // host opengl object for Points
GLuint              hCobj;   // host opengl object for Colors
struct xyzw *       hVel;    // host C++ array for Velocities
cl_mem              dPobj;   // device memory buffer for Points
cl_mem              dCobj;   // device memory buffer for Colors
cl_mem              dVel;    // device memory buffer for Velocities

cl_command_queue    CmdQueue;
cl_device_id        Device;
cl_kernel           Kernel;
cl_platform_id      Platform;
cl_program          Program;
```

Oregon State University Computer Graphics

A Deceptively-Simple Main Program

29

```
int
main( int argc, char *argv[ ] )
{
        glutInit( &argc, argv );
        InitGraphics( );
        InitLists( );
        InitCL( );
        Reset( );
        InitGlui( );
        glutMainLoop( );
        return 0;
}
```

Oregon State University Computer Graphics

GLEW – the GL Extension Wrangler

30

```
#ifdef  WIN32
  GLenum err = glewInit( );
  if( err  != GLEW_OK )
  {
        fprintf( stderr, "glewInit Error\n" );
  }
#endif
```

This *must* wait to be called until after a graphics window is open !

Why? Because creating the window is what builds the graphics context.

Oregon State University Computer Graphics

Setting up OpenCL: Querying the Existence of an OpenCL Extension

31

```
void
InitCL( )
{
        . . .

        status = clGetDeviceIDs( Platform, CL_DEVICE_TYPE_GPU, 1, &Device, NULL );
        PrintCLError( status, "clGetDeviceIDs: " );

        // since this is an opengl interoperability program,
        // check if the opengl sharing extension is supported
        // (no point going on if it isn't):
        // (we need the Device in order to ask, so we can't do it any sooner than right here)

        if(  IsCLExtensionSupported( "cl_khr_gl_sharing" )  )
        {
                fprintf( stderr, "cl_khr_gl_sharing is supported.\n" );
        }
        else
        {
                fprintf( stderr, "cl_khr_gl_sharing is not supported -- sorry.\n" );
                return;
        }
```


Querying the Existence of an OpenCL Extension

32

```
bool
IsCLExtensionSupported( const char *extension )
{
        // see if the extension is bogus:

        if( extension == NULL  ||  extension[0] == '\0' )
                return false;

        char * where = (char *) strchr( extension, ' ' );
        if( where != NULL )
                return false;

        // get the full list of extensions:

        size_t  extensionSize;
        clGetDeviceInfo(  Device, CL_DEVICE_EXTENSIONS, 0, NULL, &extensionSize  );
        char *extensions = new char [ extensionSize ];
        clGetDeviceInfo(  Device, CL_DEVICE_EXTENSIONS, extensionSize,  extensions,  NULL );

        for(  char * start = extensions ;  ;  )
        {
                where = (char *) strstr( (const char *) start, extension );
                if( where == 0 )
                {
                        delete [ ] extensions;
                        return false;
                }

                char * terminator = where + strlen(extension);   // points to what should be the separator

                if( *terminator == ' '  ||  *terminator == '\0'  ||  *terminator == '\r'  ||  *terminator == '\n' )
                {
                        delete [ ] extensions;
                        return true;
                }
                start = terminator;
        }
}
```


Setting up OpenCL: The Interoperability Context

33

```
void
InitCL( )
{
        . . .

// get the platform id:

status = clGetPlatformIDs( 1, &Platform, NULL );
PrintCLError( status, "clGetPlatformIDs: " );

// get the device id:

status = clGetDeviceIDs( Platform, CL_DEVICE_TYPE_GPU, 1, &Device, NULL );
PrintCLError( status, "clGetDeviceIDs: " );

// 3. create a special opencl context based on the opengl context:

cl_context_properties props[ ] =
{
        CL_GL_CONTEXT_KHR,          (cl_context_properties) wglGetCurrentContext( ),
        CL_WGL_HDC_KHR,             (cl_context_properties) wglGetCurrentDC( ),
        CL_CONTEXT_PLATFORM,        (cl_context_properties) Platform,
        0
};

cl_context Context = clCreateContext( props, 1, &Device, NULL, NULL, &status );
PrintCLError( status, "clCreateContext: " );
```


Setting up OpenCL: The Interoperability Context is Different for each OS (oh, good…)

34

For Windows:

```
cl_context_properties props[ ] =
{
        CL_GL_CONTEXT_KHR,          (cl_context_properties) wglGetCurrentContext( ),
        CL_WGL_HDC_KHR,             (cl_context_properties) wglGetCurrentDC( ),
        CL_CONTEXT_PLATFORM,        (cl_context_properties) Platform,
        0
};
cl_context Context = clCreateContext( props, 1, &Device, NULL, NULL, &status );
```

For Linux:

```
cl_context_properties props[ ] =
{
        CL_GL_CONTEXT_KHR,          (cl_context_properties) glXGetCurrentContext( ),
        CL_GLX_DISPLAY_KHR,         (cl_context_properties) glXGetCurrentDisplay( ),
        CL_CONTEXT_PLATFORM,        (cl_context_properties) Platform,
        0
};
cl_context Context = clCreateContext( props, 1, &Device, NULL, NULL, &status );
```

For Apple:

```
cl_context_properties props[ ] =
{
        CL_CONTEXT_PROPERTY_USE_CGL_SHAREGROUP_APPLE,
                                    (cl_context_properties) kCGLShareGroup,
        0
};
cl_context Context = clCreateContext( props, 0, 0, NULL, NULL, &status );
```


Setting up OpenCL

35

"hVel" stands for "host Velocities"
"hPobj" stands for "host Points object"
"hCobj" stands for "host Colors object"

```
void
InitCL( )
{
        . . .

// create the velocity array and the opengl vertex array buffer and color array buffer:

delete [ ] hVel;
hVel = new struct xyzw [ NUM_PARTICLES ];

glGenBuffers( 1, &hPobj );
glBindBuffer( GL_ARRAY_BUFFER, hPobj );
glBufferData( GL_ARRAY_BUFFER, 4 * NUM_PARTICLES * sizeof(float), NULL, GL_STATIC_DRAW );

glGenBuffers( 1, &hCobj );
glBindBuffer( GL_ARRAY_BUFFER, hCobj );
glBufferData( GL_ARRAY_BUFFER, 4 * NUM_PARTICLES * sizeof(float), NULL, GL_STATIC_DRAW );

glBindBuffer( GL_ARRAY_BUFFER, 0 );        // unbind the buffer

// fill those arrays and buffers:

ResetParticles( );
```


Setting the Initial Particle Parameters, I

36

```
unsigned int Seed;
...
void
ResetParticles( )
{
        glBindBuffer( GL_ARRAY_BUFFER, hPobj );
        struct xyzw *points = (struct xyzw *) glMapBuffer( GL_ARRAY_BUFFER, GL_WRITE_ONLY );
        for( int i = 0; i < NUM_PARTICLES; i++ )
        {
                points[ i ].x = Ranf( &Seed, XMIN, XMAX );
                points[ i ].y = Ranf( &Seed, YMIN, YMAX );
                points[ i ].z = Ranf( &Seed, ZMIN, ZMAX );
                points[ i ].w = 1.;
        }
        glUnmapBuffer( GL_ARRAY_BUFFER );


        glBindBuffer( GL_ARRAY_BUFFER, hCobj );
        struct rgba *colors = (struct rgba *) glMapBuffer( GL_ARRAY_BUFFER, GL_WRITE_ONLY );
        for( int i = 0; i < NUM_PARTICLES; i++ )
        {
                colors[ i ].r  = Ranf( &Seed, 0., 1. );
                colors[ i ].g = Ranf( &Seed, 0., 1. );
                colors[ i ].b = Ranf( &Seed, 0., 1. );
                colors[ i ].a = 1.;
        }
        glUnmapBuffer( GL_ARRAY_BUFFER );

        . . .
```

Setting the Initial Particle Parameters, II

37

```
        . . .
        for( int i = 0; i < NUM_PARTICLES; i++ )
        {
                hVel[ i ].x = Ranf( &Seed, VMIN, VMAX );
                hVel[ i ].y = Ranf( &Seed, 0.     , VMAX );
                hVel[ i ].z = Ranf( &Seed, VMIN, VMAX );
                hVel[ i ].w = 0.;
        }
}
```

Oregon State University
Computer Graphics

mjb – March 27, 2021

37

Setting-up the Device-Side Buffers

38

```
void
InitCL( )
{
        . . .

// 5. create the opencl version of the velocity array:

dVel = clCreateBuffer( Context, CL_MEM_READ_WRITE, 4*sizeof(float)*NUM_PARTICLES, NULL, &status );
PrintCLError( status, "clCreateBuffer: " );

// 6. write the data from the host buffers to the device buffers:

status = clEnqueueWriteBuffer( CmdQueue, dVel, CL_FALSE, 0, 4*sizeof(float)*NUM_PARTICLES, hVel, 0, NULL, NULL );
PrintCLError( status, "clEneueueWriteBuffer: " );

// 5. create the opencl version of the opengl buffers:

dPobj = clCreateFromGLBuffer( Context, CL_MEM_READ_WRITE, hPobj, &status );
PrintCLError( status, "clCreateFromGLBuffer (1)" );

dCobj = clCreateFromGLBuffer( Context, CL_MEM_READ_WRITE , hCobj, &status );
PrintCLError( status, "clCreateFromGLBuffer (2)" );
```

Note: you don't need an OpenGL-accessible buffer for the velocities. Velocities aren't needed for drawing. Velocities are only needed to update point positions. The velocity buffer can just be done internally to OpenCL.

Oregon State University
Computer Graphics

mjb – March 27, 2021

38

This is how OpenCL and OpenGL Share the Same Memory Buffer

39

```
dPobj = clCreateFromGLBuffer( Context, CL_MEM_READ_WRITE, hPobj, &status );
PrintCLError( status, "clCreateFromGLBuffer (1)" );
```

Step #1: OpenGL creates the buffer on the GPU

Step #2: OpenCL is told about it and creates a device pointer to the already-filled memory, just as if you had called **clCreateBuffer( )** and **clEnqueueWriteBuffer( )**

Oregon State University
Computer Graphics

mjb – March 27, 2021

39

Setup the Kernel Arguments…

40

```
void
InitCL( )
{
        . . .

// 10. setup the arguments to the Kernel object:

status = clSetKernelArg( Kernel, 0, sizeof(cl_mem), &dPobj );
PrintCLError( status,"clSetKernelArg (1): " );

status = clSetKernelArg( Kernel, 1, sizeof(cl_mem), &dVel );
PrintCLError( status , "clSetKernelArg (2): " );

status = clSetKernelArg( Kernel, 2, sizeof(cl_mem), &dCobj );
PrintCLError( status,  "clSetKernelArg (3): " );
```

… to Match the Kernel's Parameter List

```
kernel
void
Particle( global point * dPobj,  global vector * dVel,  global color * dCobj )
{
        . . .
}
```

Oregon State University
Computer Graphics

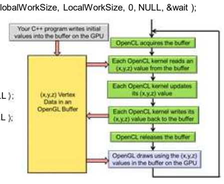
mjb – March 27, 2021

40

The OpenGL "Idle Function" Tells OpenCL to Do Its Computing

41

```
void
Animate( )
{
        // acquire the vertex buffers from opengl:

        glutSetWindow( MainWindow );
        glFinish(  );

        cl_int status;
        status = clEnqueueAcquireGLObjects( CmdQueue, 1, &dPobj, 0, NULL, NULL );
        PrintCLError( status, "clEnqueueAcquireGLObjects (1) : " );
        status = clEnqueueAcquireGLObjects( CmdQueue, 1, &dCobj, 0, NULL, NULL );
        PrintCLError( status, "clEnqueueAcquireGLObjects (2) : " );

        Wait( ); // note: only need to wait here because doing timing
        double time0 = omp_get_wtime( );

        // 11. enqueue the Kernel object for execution:

        cl_event  wait;
        status = clEnqueueNDRangeKernel( CmdQueue, Kernel, 1, NULL, GlobalWorkSize, LocalWorkSize, 0, NULL, &wait );
        PrintCLError( status, "clEnqueueNDRangeKernel:  " );

        Wait( );  // note: only need to wait here because doing timing
        double time1 = omp_get_wtime( );
        ElapsedTime  =  time1 - time0;


        clEnqueueReleaseGLObjects( CmdQueue, 1, &dCobj, 0, NULL, NULL );
        PrintCLError( status, "clEnqueueReleaseGLObjects (1): " );
        clEnqueueReleaseGLObjects( CmdQueue, 1, &dPobj, 0, NULL, NULL );
        PrintCLError( status, "clEnqueueReleaseGLObject (2): " );

        Wait( );
        glutSetWindow( MainWindow );
        glutPostRedisplay(  );
}
```

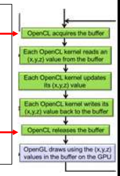


41

This is how OpenCL Manages Exclusive Access to the Memory Buffer

42

```
status = clEnqueueAcquireGLObjects( CmdQueue, 1, &dPobj, 0, NULL, NULL );

status = clEnqueueAcquireGLObjects( CmdQueue, 1, &dCobj, 0, NULL, NULL );

. . .

status = clEnqueueReleaseGLObjects( CmdQueue, 1, &dCobj, 0, NULL, NULL );

status = clEnqueueReleaseGLObjects( CmdQueue, 1, &dPobj, 0, NULL, NULL );
```



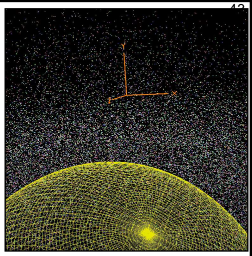
Oregon State University
Computer Graphics

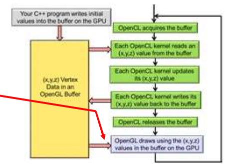
mjb – March 27, 2021

42

Redrawing the Scene: The Particles

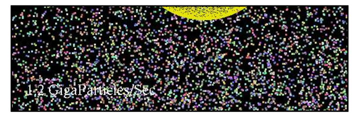

```
void
Display( )
{
        . . .

        glBindBuffer( GL_ARRAY_BUFFER, hPobj );
        glVertexPointer( 4, GL_FLOAT, 0, (void *)0 );
        glEnableClientState( GL_VERTEX_ARRAY );

        glBindBuffer( GL_ARRAY_BUFFER, hCobj );
        glColorPointer( 4, GL_FLOAT, 0, (void *)0 );
        glEnableClientState( GL_COLOR_ARRAY );

        glPointSize( 2. );
        glDrawArrays( GL_POINTS, 0, NUM_PARTICLES );
        glPointSize( 1. );

        glDisableClientState( GL_VERTEX_ARRAY );
        glDisableClientState( GL_COLOR_ARRAY );
        glBindBuffer( GL_ARRAY_BUFFER, 0 );

        glutSwapBuffers( );
        glFlush( );
}
```





Redraw the Scene: The Performance


```
void
Display( )
{
        . . .

        if( ShowPerformance )
        {
                char str[128];
                sprintf( str, "%6.1f GigaParticles/Sec", (float)NUM_PARTICLES/ElapsedTime/1000000000. );
                glDisable( GL_DEPTH_TEST );
                glMatrixMode( GL_PROJECTION );
                glLoadIdentity( );
                gluOrtho2D( 0., 100.,     0., 100. );
                glMatrixMode( GL_MODELVIEW );
                glLoadIdentity( );
                glColor3f( 1., 1., 1. );
                DoRasterString( 5., 5., 0., str );
        }
```



13. Clean-up


```
void
Quit( )
{
        Glui->close( );
        glutSetWindow( MainWindow );
        glFinish( );
        glutDestroyWindow( MainWindow );


        // 13. clean everything up:

        clReleaseKernel(          Kernel   );
        clReleaseProgram(         Program  );
        clReleaseCommandQueue(  CmdQueue );
        clReleaseMemObject(       dPobj  );
        clReleaseMemObject(       dCobj  );

        exit( 0 );
}
```

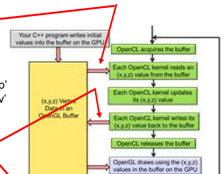

particles.cl, I


```
typedef  float4  point;          // x, y, z – the w is unused
typedef  float4  vector;         // vx, vy, vz – the w is unused
typedef  float4  color;          // r, g, b – the w is unused
typedef  float4  sphere;         // xc, yc, zc, r

// despite what we think of the 4 components as representing,
// they are all referenced as .x, .y, .z, and .w

constant float4 G            = (float4) ( 0., -9.8, 0., 0. );            // gravity
constant float  DT           = 0.1;                                       // time step
constant sphere Sphere1 = (sphere)( -100., -800., 0.,  600. );            // xc. yc, zc, r


bool
IsInsideSphere( point p, sphere s )
{
        float r = fast_length( p.xyz - s.xyz );
        return  ( r < s.w );
}
```

points, vectors, colors, and spheres are all represented as float4's. The typedefs help the program's readability by showing what that float4 is actually representing.

particles.cl, II


```
kernel
void
Particle(  global point * dPobj,  global vector * dVel,  global color * dCobj  )
{
        int gid = get_global_id( 0 );          // particle #

        point p   = dPobj[gid];
        vector v = dVel[gid];

        point pp   = p + v*DT + G * (point)(.5*DT*DT);  // p'
        vector vp = v + G*DT;                             // v'
        pp.w = 1.;
        vp.w = 0.;

        if(   IsInsideSphere( pp, Sphere1 )   )
        {
                vp = BounceSphere( p, v, Sphere1 );
                pp = p + vp*DT + G * (point)( .5*DT*DT );
        }

        dPobj[gid] = pp;
        dVel[gid]   = vp;
}
```



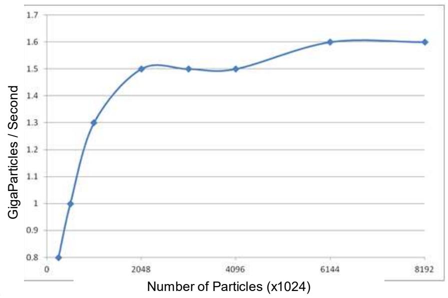
Computer Graphics Trick Alert: Making the bounce happen from the surface of the sphere is time-consuming to compute. Instead, bounce from the previous position in space. If DT is small enough, nobody will ever know…

particles.cl, III


```
vector
Bounce( vector in, vector n )
{
        n.w = 0.;
        n = fast_normalize( n );              // make it a unit vector

        // this is the vector equation for "angle of reflection equals angle of incidence":
        vector  out = in   -  n * (vector)( 2.*dot( in.xyz,  n.xyz  ) );
                // adding or subtracting 2 float4's gives you another float4
                // multiplying 2 float4's gives you another float4
                // when you want a dot product, use the dot( ) function
        out.w = 0.;
        return out;
}


vector
BounceSphere( point p, vector in,  sphere s )
{
        vector n;
        n.xyz = p.xyz - s.xyz;
                // the vector from the sphere center to the point is the normal
        return Bounce( in, n );
}
```

Remember from the OpenCL Assembly Language notes:
"The sqrt($x^2+y^2+z^2$) assembly code is amazingly involved. I suspect it is an issue of maintaining highest precision. Use **fast_sqrt( )**, **fast_normalize( ),** and **fast_length( )** when you can."

Jane Parallel's Performance



Oregon State University
Computer Graphics