OpenGL Compute Shaders

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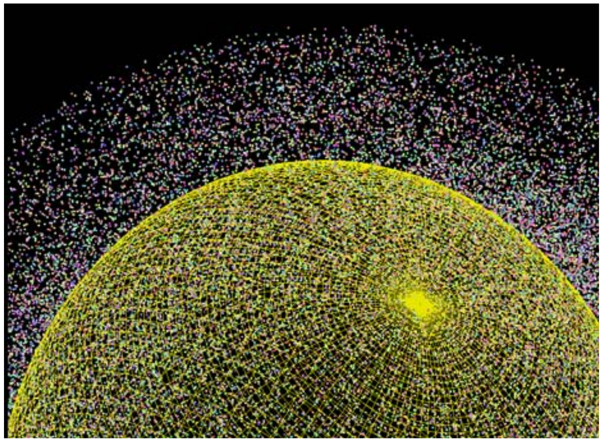
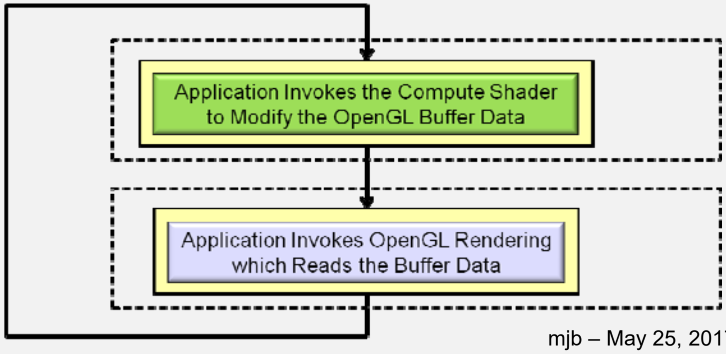
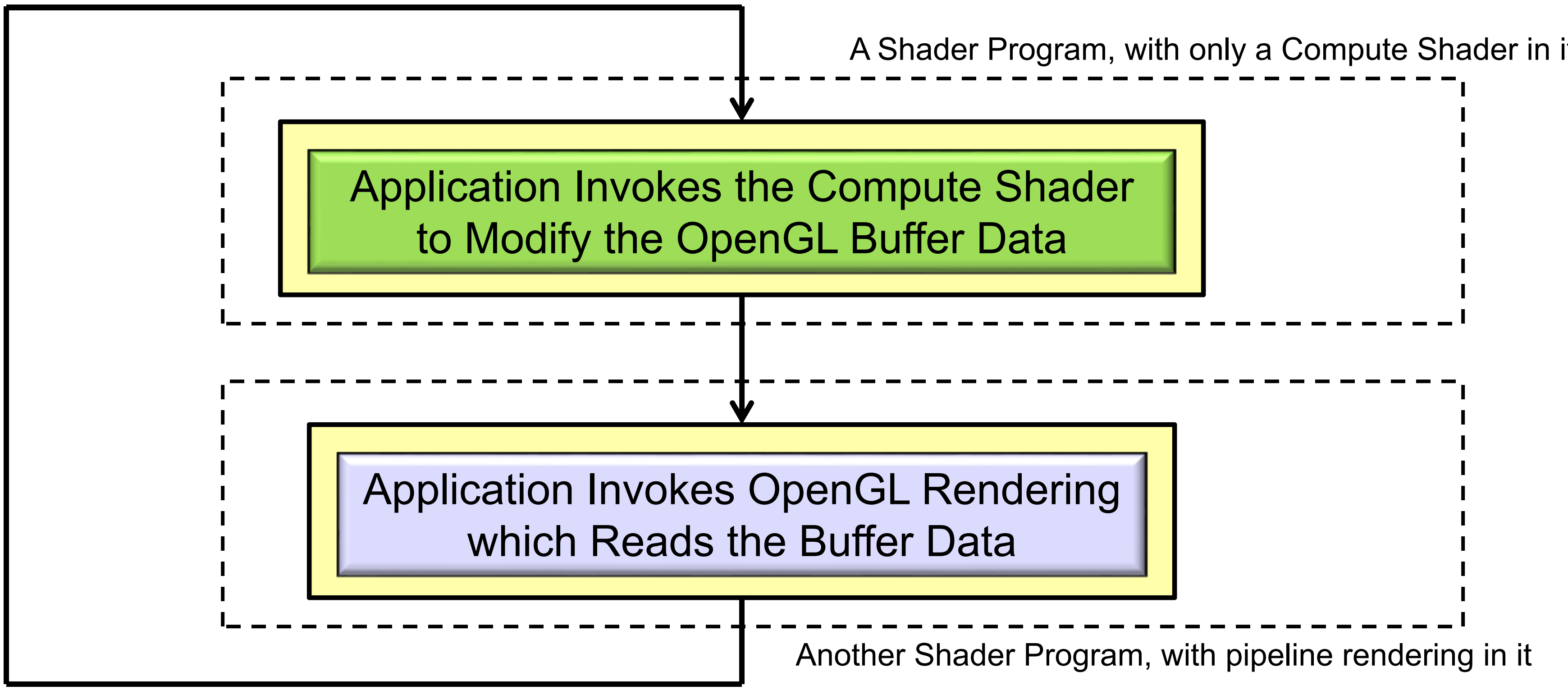




OpenGL Compute Shader – the Basic Idea



Why Not Just Use OpenCL Instead?

OpenCL is *great*! It does a super job of using the GPU for general-purpose data-parallel computing. And, OpenCL is more feature-rich than OpenGL compute shaders. So, why use Compute Shaders *ever* if you've got OpenCL? Here's what I think:

- OpenCL requires installing a separate driver and separate libraries. While this is not a huge deal, it does take time and effort. When everyone catches up to OpenGL 4.3, Compute Shaders will just "be there" as part of core OpenGL.
- Compute Shaders use the GLSL language, something that all OpenGL programmers should already be familiar with (or will be soon).
- Compute shaders use the same context as does the OpenGL rendering pipeline. There is no need to acquire and release the context as OpenGL+OpenCL must do.
- I'm assuming that calls to OpenGL compute shaders are more lightweight than calls to OpenCL kernels are. (true?) This should result in better performance. (true? how much?)
- Using OpenCL is somewhat cumbersome. It requires a lot of setup (queries, platforms, devices, queues, kernels, etc.). Compute Shaders look to be more convenient. They just kind of flow in with the graphics.

The bottom line is that I will continue to use OpenCL for the big, bad stuff. But, for lighter-weight data-parallel computing that interacts with graphics, I will use the Compute Shaders.

I suspect that a good example of a lighter-weight data-parallel graphics-related application is a **particle system**. This will be shown here in the rest of these notes. I hope I'm right.

If I Know GLSL, What Do I Need to Do Differently to Write a Compute Shader?

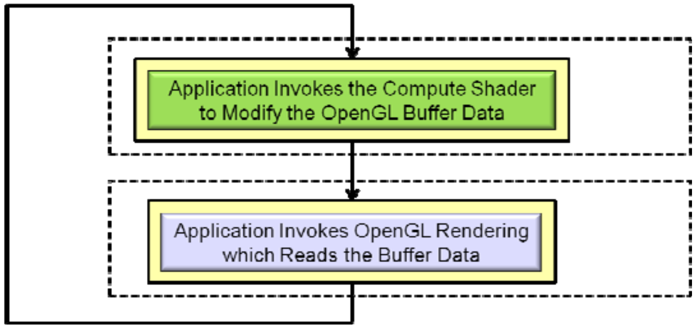
Not much:

1. A Compute Shader is created just like any other GLSL shader, except that its type is GL_COMPUTE_SHADER (duh…). You compile it and link it just like any other GLSL shader program.

2. A Compute Shader must be in a shader program all by itself. There cannot be vertex, fragment, etc. shaders in there with it. (why?)

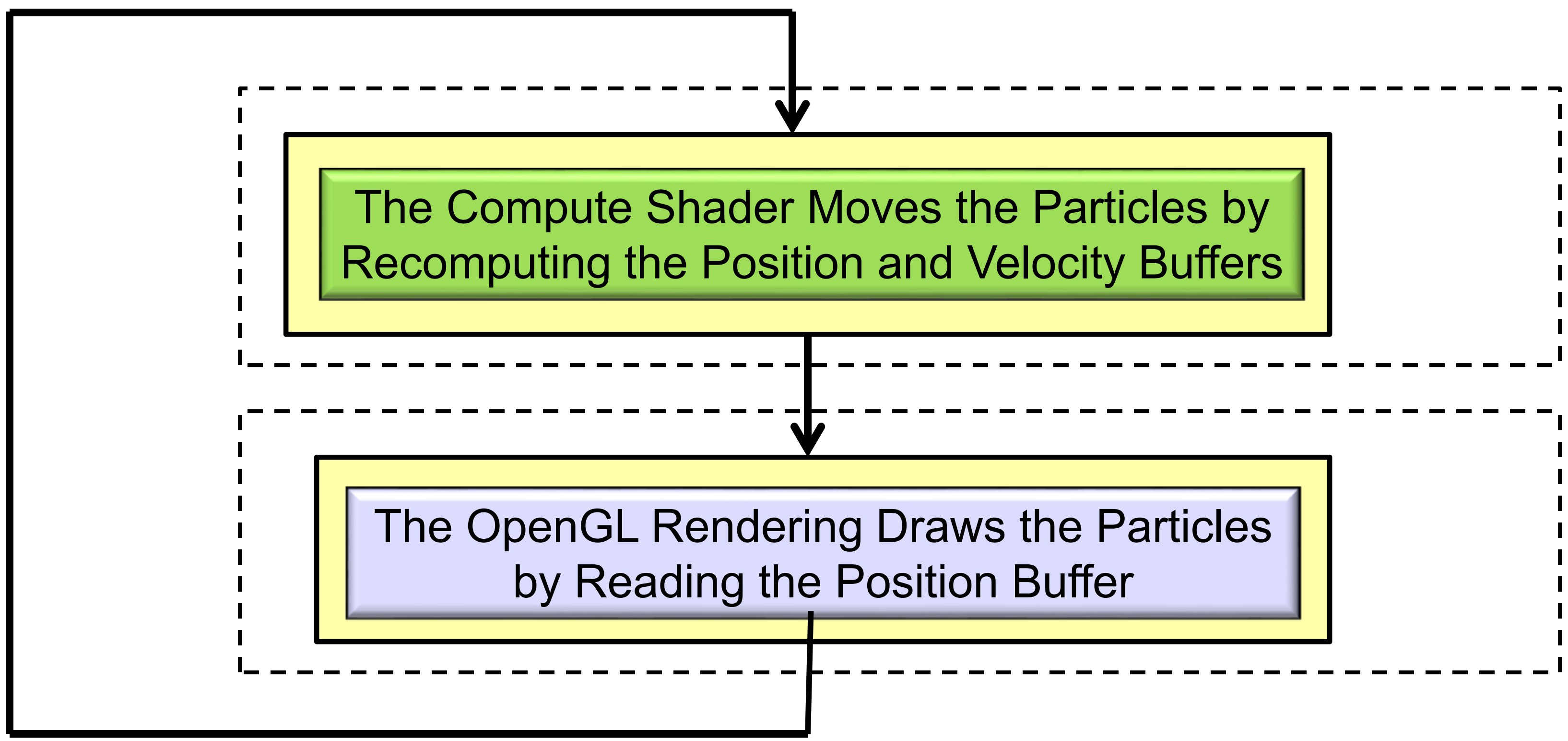
3. A Compute Shader has access to uniform variables and buffer objects, but cannot access any pipeline variables such as attributes or variables from other stages. It stands alone.

4. A Compute Shader needs to declare the number of work-items in each of its work-groups in a special GLSL *layout* statement.



More information on items 3 and 4 are coming up . . .

The Example We Are Going to Use Here is a *Particle System*



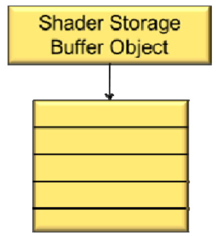
Setting up the Shader Storage Buffer Objects in Your C Program

```
#define NUM_PARTICLES        1024*1024        // total number of particles to move
#define WORK_GROUP_SIZE            128        // # work-items per work-group

struct pos
{
        float x, y, z, w;        // positions
};

struct vel
{
        float vx, vy, vz, vw;    // velocities
};

struct color
{
        float r, g, b, a;        // colors
};

// need to do the following for both position, velocity, and colors of the particles:

GLuint  posSSbo;
GLuint  velSSbo
GLuint  colSSbo;
```

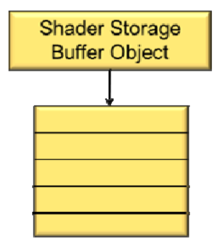
Note that .w and .vw are not actually needed. But, by making these structure sizes a multiple of 4 floats, it doesn't matter if they are declared with the std140 or the std430 qualifier. I think this is a good thing. (is it?)

Setting up the Shader Storage Buffer Objects in Your C Program

```
glGenBuffers( 1, &posSSbo);
glBindBuffer( GL_SHADER_STORAGE_BUFFER, posSSbo );
glBufferData( GL_SHADER_STORAGE_BUFFER, NUM_PARTICLES * sizeof(struct pos), NULL, GL_STATIC_DRAW );

GLint bufMask = GL_MAP_WRITE_BIT | GL_MAP_INVALIDATE_BUFFER_BIT ;          // the invalidate makes a big difference when re-writing

struct pos *points = (struct pos *) glMapBufferRange( GL_SHADER_STORAGE_BUFFER, 0, NUM_PARTICLES * sizeof(struct pos), bufMask );
for( int i = 0; i < NUM_PARTICLES; i++ )
{
        points[ i ].x = Ranf( XMIN, XMAX );
        points[ i ].y = Ranf( YMIN, YMAX );
        points[ i ].z = Ranf( ZMIN, ZMAX );
        points[ i ].w = 1.;
}
```




```
glUnmapBuffer( GL_SHADER_STORAGE_BUFFER );

glGenBuffers( 1, &velSSbo);
glBindBuffer( GL_SHADER_STORAGE_BUFFER, velSSbo );
glBufferData( GL_SHADER_STORAGE_BUFFER, NUM_PARTICLES * sizeof(struct vel), NULL, GL_STATIC_DRAW );

struct vel *vels = (struct vel *) glMapBufferRange( GL_SHADER_STORAGE_BUFFER, 0, NUM_PARTICLES * sizeof(struct vel), bufMask );
for( int i = 0; i < NUM_PARTICLES; i++ )
{
        vels[ i ].vx = Ranf( VXMIN, VXMAX );
        vels[ i ].vy = Ranf( VYMIN, VYMAX );
        vels[ i ].vz = Ranf( VZMIN, VZMAX );
        vels[ i ].vw = 0.;
}
```



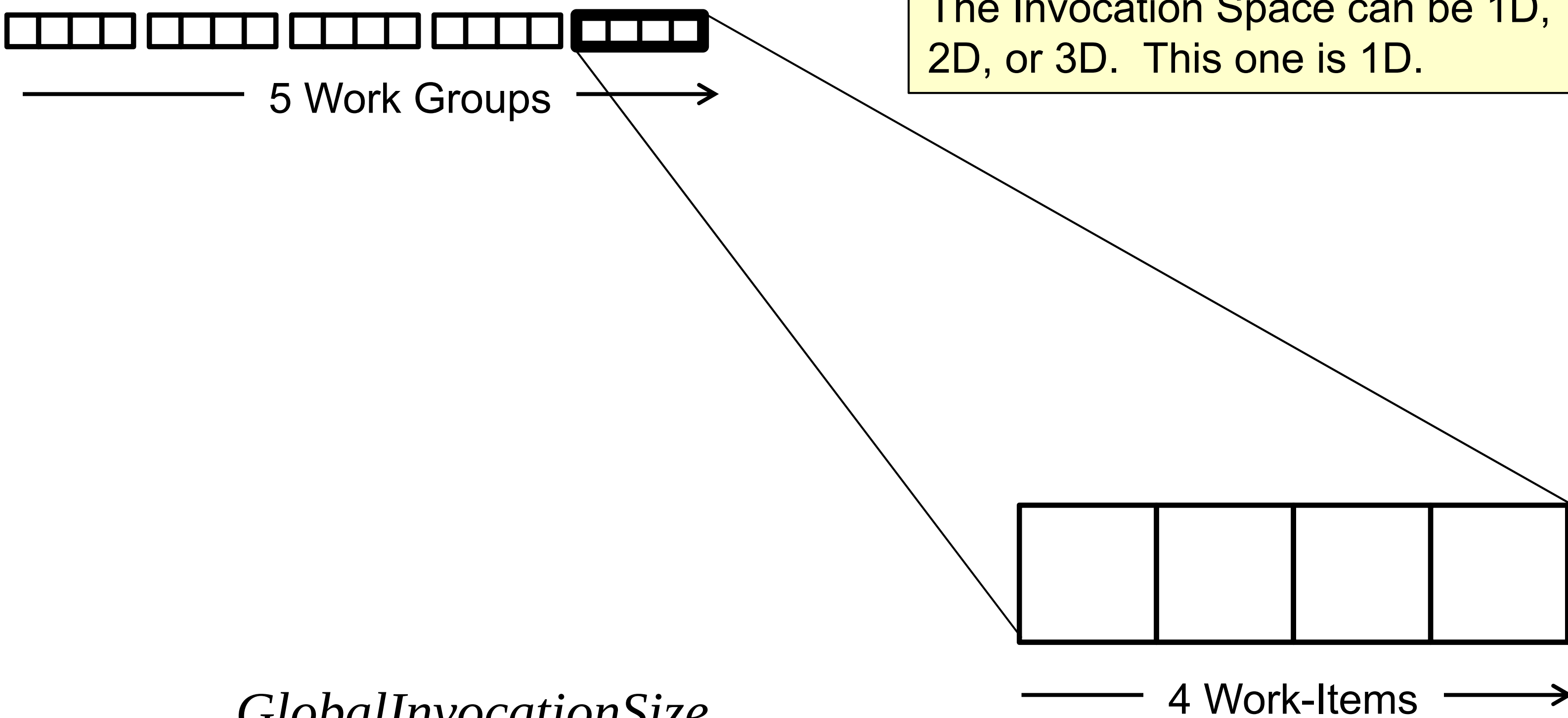

```
glUnmapBuffer( GL_SHADER_STORAGE_BUFFER );
```

The same would possibly need to be done for the color shader storage buffer object

The Data Needs to be Divided into Large Quantities call *Work-Groups*, each of which is further Divided into Smaller Units Called *Work-Items*

20 total items to compute:

The Invocation Space can be 1D, 2D, or 3D. This one is 1D.



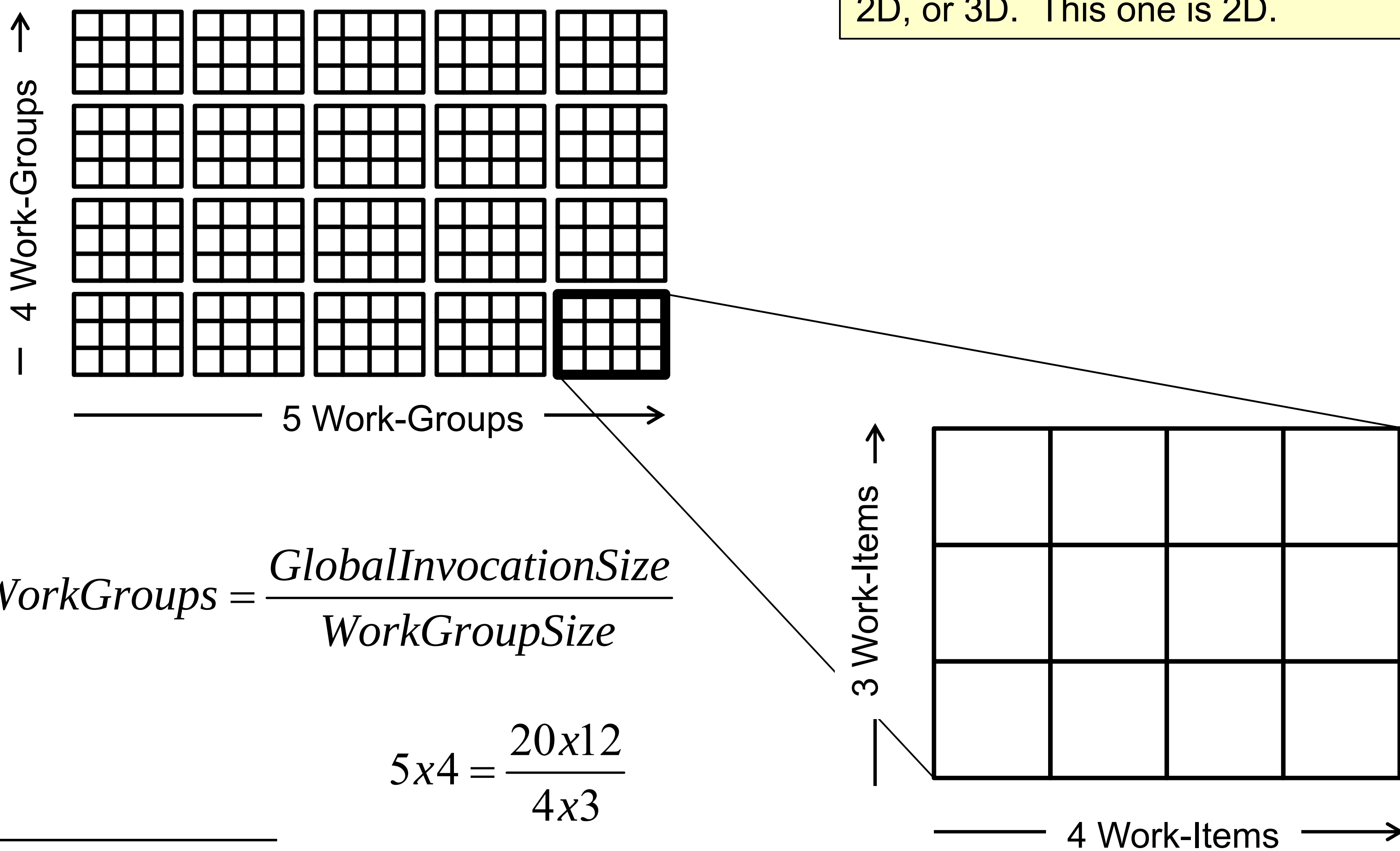
$$\#WorkGroups = \frac{GlobalInvocationSize}{WorkGroupSize}$$

$$5x4 = \frac{20}{4}$$

The Data Needs to be Divided into Large Quantities call Work-Groups, each of which is further Divided into Smaller Units Called Work-Items

20x12 (=240) total items to compute:

The Invocation Space can be 1D, 2D, or 3D. This one is 2D.

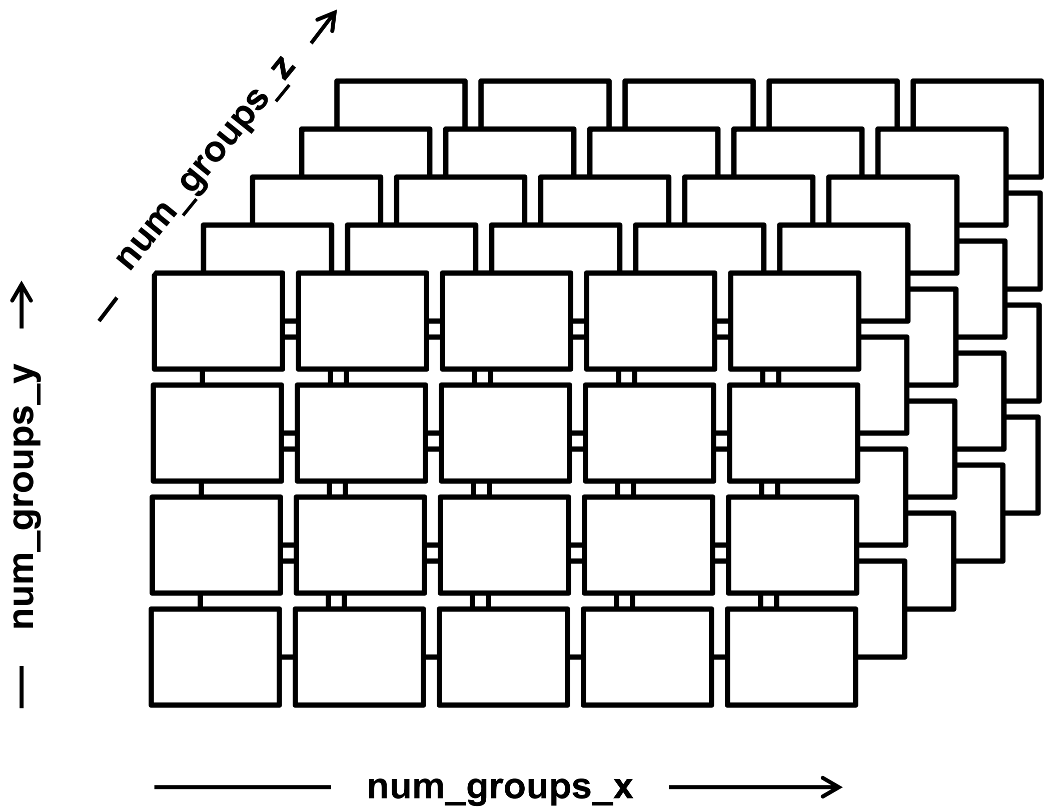


$$\#WorkGroups = \frac{GlobalInvocationSize}{WorkGroupSize}$$

$$5x4 = \frac{20x12}{4x3}$$

Running the Compute Shader from the Application

```
void glDispatchCompute( num_groups_x, num_groups_y, num_groups_z );
```

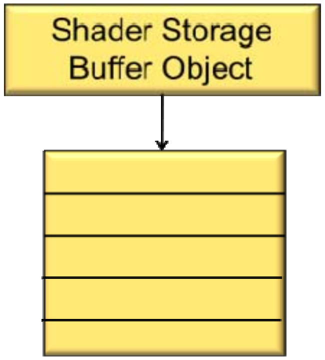


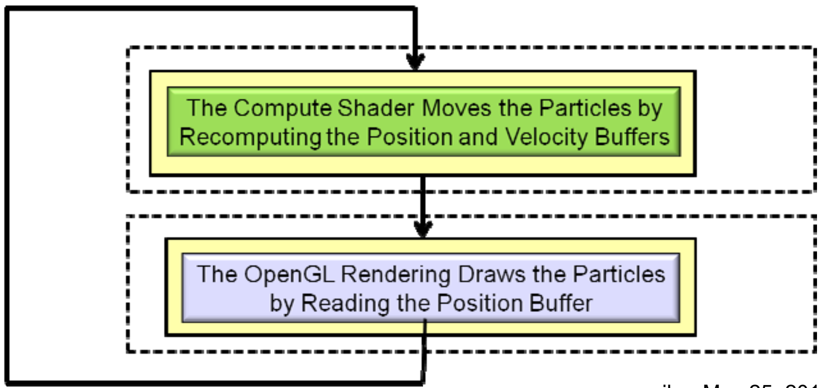
If the problem is 2D, then
num_groups_z = 1

If the problem is 1D, then
num_groups_y = 1 and
num_groups_z = 1

Invoking the Compute Shader in Your C/C++ Program


```
glBindBufferBase( GL_SHADER_STORAGE_BUFFER,  4,  posSSbo );
glBindBufferBase( GL_SHADER_STORAGE_BUFFER,  5,  velSSbo  );
glBindBufferBase( GL_SHADER_STORAGE_BUFFER,  6,  colSSbo  );

        . . .

glUseProgram( MyComputeShaderProgram );
glDispatchCompute( NUM_PARTICLES  / WORK_GROUP_SIZE, 1,  1 );
glMemoryBarrier( GL_SHADER_STORAGE_BARRIER_BIT );

        . . .

glUseProgram( MyRenderingShaderProgram );
glBindBuffer( GL_ARRAY_BUFFER, posSSbo );
glVertexPointer( 4, GL_FLOAT, 0, (void *)0 );
glEnableClientState( GL_VERTEX_ARRAY );
glDrawArrays( GL_POINTS, 0, NUM_PARTICLES );
glDisableClientState( GL_VERTEX_ARRAY );
glBindBuffer( GL_ARRAY_BUFFER, 0 );
```





Special Pre-set Variables in the Compute Shader

in	**uvec3**	**gl_NumWorkGroups ;**	Same numbers as in the *glDispatchCompute* call
const	**uvec3**	**gl_WorkGroupSize ;**	Same numbers as in the *layout* local_size_*
in	**uvec3**	**gl_WorkGroupID ;**	Which workgroup this thread is in
in	**uvec3**	**gl_LocalInvocationID ;**	Where this thread is in the current workgroup
in	**uvec3**	**gl_GlobalInvocationID ;**	Where this thread is in *all* the work items
in	**uint**	**gl_LocalInvocationIndex ;**	1D representation of the gl_LocalInvocationID (used for indexing into a shared array)

0 ≤ gl_WorkGroupID ≤ gl_NumWorkGroups – 1

0 ≤ gl_LocalInvocationID ≤ gl_WorkGroupSize – 1

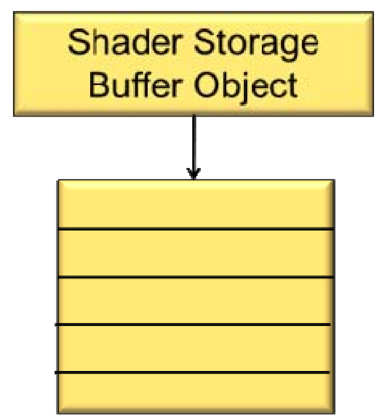
gl_GlobalInvocationID = gl_WorkGroupID * gl_WorkGroupSize + gl_LocalInvocationID

gl_LocalInvocationIndex = gl_LocalInvocationID.z * gl_WorkGroupSize.y * gl_WorkGroupSize.x +
gl_LocalInvocationID.y * gl_WorkGroupSize.x +
gl_LocalInvocationID.x

The Particle System Compute Shader -- Setup

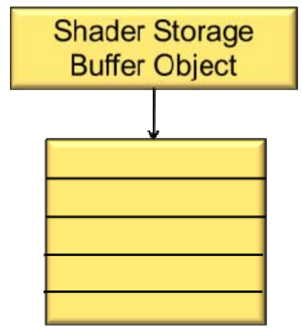
```
#version 430 compatibility
#extension GL_ARB_compute_shader :                 enable
#extension GL_ARB_shader_storage_buffer_object :   enable;

layout( std140, binding=4 )  buffer  Pos
{
                vec4  Positions[   ];                    // array of structures
};

layout( std140, binding=5 )  buffer   Vel
{
                vec4  Velocities[   ];                   // array of structures
};

layout( std140, binding=6 )  buffer  Col
 {
                vec4  Colors[   ];                       // array of structures
};

layout( local_size_x = 128,  local_size_y = 1, local_size_z = 1 )   in;
```

You can use the empty brackets, but only on the *last* element of the buffer. The actual dimension will be determined for you when OpenGL examines the size of this buffer's data store.



The Particle System Compute Shader – The Physics

```
const  vec3  G        =  vec3( 0., -9.8, 0. );
const  float   DT     =  0.1;

        . . .

uint  gid = gl_GlobalInvocationID.x;          // the .y and .z are both 1 in this case

vec3 p  = Positions[  gid  ].xyz;
vec3 v  = Velocities[  gid  ].xyz;

vec3  pp = p + v*DT + .5*DT*DT*G;
vec3  vp = v + G*DT;

Positions[  gid  ].xyz  = pp;
Velocities[  gid  ].xyz = vp;
```

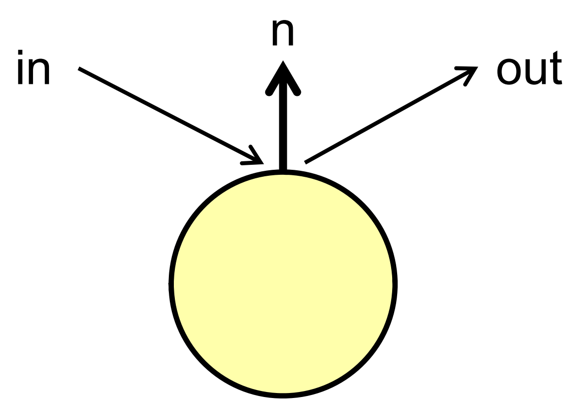


$$p' = p + v \cdot t + \frac{1}{2} G \cdot t^2$$

$$v' = v + G \cdot t$$

The Particle System Compute Shader – How About Introducing a Bounce?

```
const vec4 SPHERE =  vec4( -100., -800., 0.,  600. );  // x, y, z, r
                                                        // (could also have passed this in)

vec3
Bounce( vec3 vin, vec3 n )
{
        vec3 vout = reflect( vin, n );
        return vout;
}

vec3
BounceSphere( vec3 p, vec3 v, vec4 s )
{
        vec3 n = normalize( p - s.xyz );
        return Bounce( v, n );
}

bool
IsInsideSphere( vec3 p, vec4 s )
{
        float r = length( p - s.xyz );
        return  (  r < s.w  );
}
```



The Particle System Compute Shader – How About Introducing a Bounce?

```
uint  gid = gl_GlobalInvocationID.x;                // the .y and .z are both 1 in this case

vec3 p  = Positions[  gid  ].xyz;
vec3 v  = Velocities[  gid  ].xyz;

vec3  pp = p + v*DT + .5*DT*DT*G;
vec3  vp = v + G*DT;

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

Positions[   gid  ].xyz = pp;
Velocities[  gid  ].xyz = vp;
```

$$p' = p + v \cdot t + \frac{1}{2} G \cdot t^2$$

$$v' = v + G \cdot t$$

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

The Bouncing Particle System Compute Shader – What Does It Look Like?