L13: Sorting and OpenGL Interface

Administrative

- Midterm coming
  - In class March 25, can bring one page of notes
  - Review notes, readings and review lecture
  - Prior exams are posted
- Design Review
  - Intermediate assessment of progress on project, oral and short
  - In class on April 1
- Final projects
  - Poster session, April 24 (dry run April 22)
  - Final report, May 1

Sources for Today's Lecture

OpenGL Rendering
http://www.nvidia.com/content/cudazone/download/Advanced_CUDA_Training_NVISION08.pdf

Chapter 3.2.7.1 in the CUDA Programming Guide

Sorting

- (Bitonic sort in CUDA SDK)
- Erik Sintorn, Ulf Assarson. *Fast Parallel GPU-Sorting Using a Hybrid Algorithm.Journal of Parallel and Distributed Computing, Volume 68, Issue 10, Pages 1381-1388, October 2008.*

http://www.ce.chalmers.se/~uffe/hybridsortElsevier.pdf

OpenGL Rendering

- OpenGL buffer objects can be mapped into the CUDA address space and then used as global memory
  - Vertex buffer objects
  - Pixel buffer objects
- Allows direct visualization of data from computation
  - No device to host transfer
  - Data stays in device memory –very fast compute / viz cycle
- Data can be accessed from the kernel like any other global data (in device memory)

OpenGL Interoperability

1. Register a buffer object with CUDA
   - **cudaGLRegisterBufferObject(GLuintbuffObj)**;
   - OpenGL can use a registered buffer only as a source
   - Unregister the buffer prior to rendering to it by OpenGL
2. Map the buffer object to CUDA memory
   - **cudaGLMapBufferObject(void**devPtr, GLuintbuffObj);**
   - Returns an address in global memory Buffer must be registered prior to mapping
3. Launch a CUDA kernel to process the buffer

• Unmap the buffer object prior to use by OpenGL
   - **cudaGLUnmapBufferObject(GLuintbuffObj);**

4. Unregister the buffer object
   - **cudaGLUnregisterBufferObject(GLuintbuffObj);**
   - Optional: needed if the buffer is a render target
5. Use the buffer object in OpenGL code

Example from simpleGL in SDK

1. GL calls to create and initialize buffer, then registered with CUDA:

```
// create buffer object
glGenBuffers( 1, vbo);
glBindBuffer( GL_ARRAY_BUFFER, *vbo);

// initialize buffer object
unsigned int size = mesh_width * mesh_height * 4 * sizeof( float)*2;
glBufferData( GL_ARRAY_BUFFER, size, 0, GL_DYNAMIC_DRAW);
glBindBuffer( GL_ARRAY_BUFFER, 0);

// register buffer object with CUDA
cudaGLRegisterBufferObject(*vbo);
```

Example from simpleGL in SDK, cont.

2. Map OpenGL buffer object for writing from CUDA

```
float4 *dptr;
cudaGLMapBufferObject( (void**)&dptr, vbo));
```

3. Execute the kernel to compute values for dptr

```
dim3 block(8, 8, 1);
dim3 grid(mesh_width / block.x, mesh_height /
  block.y, 1);
kernel<<< grid, block>>>(dptr, mesh_width,
  mesh_height, anim);
```

4. Unregister the OpenGL buffer object and return to Open GL

```
cudaGLUnmapBufferObject( vbo);
```

Key issues in sorting?

- Data movement requires significant memory bandwidth
- Managing global list may require global synchronization
- Very little computation, memory bound

Hybrid Sorting Algorithm, Key Ideas

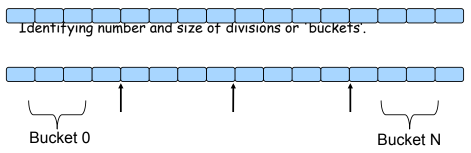
- Imagine a "recursive" algorithm
  - Use different strategies for different numbers of elements
  - Algorithm depends on how much work, and how much storage was required
- Here we use different strategies for different-sized lists
  - Very efficient sort for float4
  - Use shared memory for sublists
  - Use global memory to create pivots

Hybrid Sorting Algorithm (Sintorn and Assarsson)

- Each pass:
  - Merge 2L sorted lists into L sorted lists
- Three parts:
  - Histogramming: to split input list into L independent sublists for Pivot Points
  - Bucketsort: to split into lists than can be sorted using next step
  - Vector-Mergesort:
    - Elements are grouped into 4-float vectors and a kernel sorts each vector internally
    - Repeat until sublist is sorted
- Results:
  - 20% improvement over radix sort, best GPU algorithm
  - 6-14 times faster than quicksort on CPU

Sample Sort (Detailed slides)

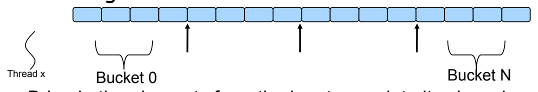
- Divide and Conquer
  - Input as an array
  - Identifying number and size of divisions or 'buckets'.



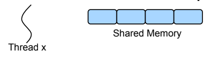
- Histogramming in global memory constructs buckets for the elements.
- A priori select pivot values – if this results in load imbalance, update pivots and repeat

Hybrid Sort

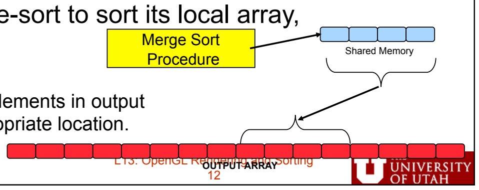
- To handle the buckets each thread does the following:



- Bring in the elements from the input array into its shared memory

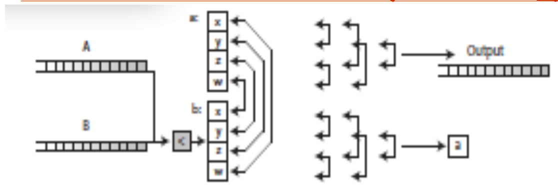


- Use merge-sort to sort its local array,



- Pushes the elements in output array in appropriate location.

Sort two vectors from A & B (Bitonic Sort)



```
// get the four lowest floats
a.xyzw = (a.xyzw < b.wzyx) ? a.xyzw : b.wzyx
// get the four highest floats
b.xyzw = (b.xyzw >= a.wzyx) ? b.xyzw : a.wzyx

Call sortElements(a);
Call sortElements(b);
```

Key Computation: Vector MergeSort

Idea: Use vector implementation to load 4 elements at a time, and "swizzling" to move vector elements around

Output: a sorted vector of four elements for

[2, 6, 3, 1]

```
// Bitonic sort within a vector
// Meaning: r.xyzw is original order; r.wzyx is reversed order
sortElements(float4 r) {
   r = (r.xyzw > r.yxwz) ? r.yyww : r.xxzz
   r = (r.xyzw > r.zwxy) ? r.zwzw : r.xyxy
   r = (r.xyzw > r.xzyw) ? r.xzzw : r.xyyw
}
```

Working Through An Example

```
// Bitonic sort within a vector
// Meaning: r.xyzw is original order; r.wzyx is reversed order
sortElements(float4 r) {
   r = (r.xyzw > r.yxwz) ? r.yyww : r.xxzz
   r = (r.xyzw > r.zwxy) ? r.zwzw : r.xyxy
   r = (r.xyzw > r.xzyw) ? r.xzzw : r.xyyw
}
```

Sort lowest four elements, [2, 6, 3, 1]

[2,6,3,1] > [6,2,1,3] becomes [2,6,1,3]
[2,6,1,3] > [1,3,2,6] becomes [1,3,2,6]
[1,3,2,6] > [1,2,3,6] becomes [1,2,3,6]

Working Through An Example

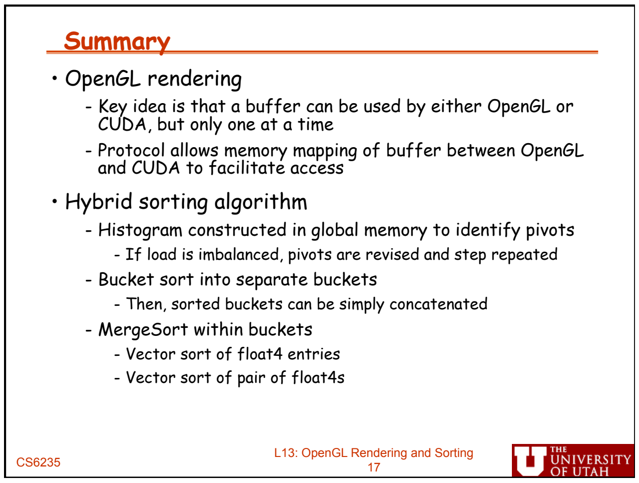
// get four lowest elements

a.xyzw = (a.xyzw < b.wzyx) ? a.xyzw : b.wzyx

a = {2,6,9,10}

b = {1,3,8,11}

```
[2,6,9,10] < [11,8,3,1] becomes
  2 < 11 ? 2 : 11   -> 2
  6 <  8 ? 6 : 8    -> 6
  9 < 3  ? 9:  3 -> 3
  10 < 1 ? 10 : 1 -> 1
```



Summary

- OpenGL rendering
  - Key idea is that a buffer can be used by either OpenGL or CUDA, but only one at a time
  - Protocol allows memory mapping of buffer between OpenGL and CUDA to facilitate access
- Hybrid sorting algorithm
  - Histogram constructed in global memory to identify pivots
    - If load is imbalanced, pivots are revised and step repeated
  - Bucket sort into separate buckets
    - Then, sorted buckets can be simply concatenated
  - MergeSort within buckets
    - Vector sort of float4 entries
    - Vector sort of pair of float4s