

Programming for Performance: Assignment 4

Patrick Lam

Due: April 8, 2013

Let me know if you want a different group from A3.

In this assignment, you will write OpenCL code to implement parts of an N -body simulation. The first part consists of converting some sequential C code into OpenCL, while the second part requires you to improve the algorithm by making approximations for points that are far away.

We'll be starting with the code from GPU Gems 3¹. I also found an OpenCL N -body simulation code on the Internet². Also, you can read Andrew Cooke's notes; they are similar to my OpenCL lecture (L20), but they may make more sense to you³.

Using OpenCL on ece459-1 should be fairly straightforward as long as you have the right compiler options. The Makefile I've provided should work for you. You are also free to use OpenCL on your own computer, if you choose.

Use `provided-assignment-04.tar.gz`⁴ as a template for your submission. Using the same directory structure, submit C++ files containing OpenCL versions (naive and optimized) of the N -body code, along with a brief report (about half a page).

Part 1: Brute-force approach (50 points)

The easiest way to do an N -body simulation is to compute the effects of all points on each other. I've posted some sequential code (based on the GPU Gems code) to calculate the forces for one time-step. Your first task is to convert this code to OpenCL. We will evaluate the correctness and efficiency of your conversion. OpenCL can assign workgroups automatically.

Part 2: Far-field approximations (50 points)

Algorithmic improvements are important. In this part, you will speed up the force calculation by crudely estimating the forces exerted by faraway points. The idea is to divide the points into a number of bins. (Real codes would use

¹http://http.developer.nvidia.com/GPUGems3/gpugems3_ch31.html

²http://www.browndeertechnology.com/docs/BDT_OpenCL_Tutorial_NBody-rev3.html

³<http://www.acooke.org/cute/APractical0.html>

⁴<http://patricklam.ca/p4p/files/provided-assignment-04.tar.gz>

quadtrees or octrees to store, and thus find, the closest points⁵). You will then compute the center of mass for each bin and add the force exerted by the center of mass for faraway bins to the force exerted by individual particles for nearby particles.

Computing centers-of-masses for bins (20 points). Instead of finding the k nearest points, we will divide space into a fixed number of bins and compute the center of mass of each of these bins. For nearby bins, we do the $O(n^2)$ calculation; for further bins, we compute forces for each bin. Conveniently, for this assignment I've divided space into $[0, 1000]^3$, so we can take bins which are cubes of length 100. This gives 1000 bins.

I recommend that you create a 3-dimensional array `cm` of `float4s`⁶ to store centers-of-mass. The `x`, `y` and `z` components contain the average position of the center of mass of a bin, while the `w` component stores the total mass. Compute all of the masses in parallel: create one thread per bin, and add a point's position if it belongs to the bin, e.g.

```
int xbin, ybin, zbin; // initialize with bin coordinates
int b;
for (i = 0; i < POINTS; i++) {
    if (pts[i] in bin coordinates) {
        cm[b].x += pts[i].x; // y, z too
        cm[b].w += 1.0f;
    }
}
cm[b].x /= cm[b].w; // etc
```

Note that this parallelizes with the number of bins.

Bin Contents (20 points). For the next step, you'll also need to keep track of the points in each bin. Fortunately, you've collected the number of points in each bin, so you can allocate the appropriate amount of memory to store the points in a two-dimensional array `binPts`. In a second phase, iterate over all bins again, this time putting coordinates into the proper element of `binPts`.

Computing Forces (10 points). The payoff from all these calculations is to save time while calculating forces. Let's arbitrarily say that we'll compute exact forces for the points in the same bin and the directly-adjacent bins in each direction (think of a Rubik's Cube; that makes 27 bins in all, with 6 bins sharing a square, 8 bins sharing an edge, and 12 bins sharing a point with the center bin). If there is no adjacent bin, then there are no points in that bin.

Using the data that you've computed so far, write OpenCL code to estimate forces for each point. This has two parts. In the first part, compute forces

⁵For a very readable summary of the Barnes-Hut algorithm, see <http://arborjs.org/docs/barnes-hut>.

⁶When I did the assignment, a `float` versus `float4` mismatch took me a long time to debug.

directly for the points in the 27 adjacent bins. In the second part, sum the forces from the centers of mass.

There is a caveat: it's easier to add forces from all centers of mass, whether nearby or far away. I recommend that you add forces from centers of mass, and then subtract away the forces that you're double-counting:

```
// add negative forces to not double-count adjacent bins
negBin.x = 2*myPosition.x-globalCM[bin].x;
negBin.y = 2*myPosition.y-globalCM[bin].y;
negBin.z = 2*myPosition.z-globalCM[bin].z;
negBin.w = globalCM[bin].w;
bodyBodyInteraction(myPosition, negBin, pacc);
```

Finally, compare the performance of part 1 and part 2.

What to hand in. For part 1, hand in OpenCL code (using the C++ bindings). For part 2, write about your design choices and results (about half a page), and hand that in along with your OpenCL code. I recommend handing in both C++ files (for parts 1 and 2) and the diffs; that will make it easier for us to mark.

Timings

Here's some timings from when I last did this assignment.

```
plam@ece459-2 ~/a4-skel $ time ./nbody-seq > unopt-out
real1m50.225s
user1m50.220s
sys0m0.000s
```

```
plam@ece459-2 ~/a4-skel $ time ./nbody-seq-opt > opt-out
real0m17.307s
user0m17.270s
sys0m0.030s
```

```
plam@ece459-2 ~/a4-skel $ time ./nbody > opencl-out2
real0m1.426s
user0m0.460s
sys0m0.190s
```

```
plam@ece459-2 ~/a4-skel $ time ./nbody-opt > opencl-out
real0m1.003s
user0m0.520s
sys0m0.190s
```

We'll see how much faster machines have gotten in the two years since.