

Programming for Performance: Assignment 4

(v2)*

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This is an individual assignment.

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.

I will also upload instructions on how to use the `ece459-N` computers to develop and test your code in the `a4notes` document. You are also free to use OpenCL on your own computer, if you choose.

The sample code is at <http://patricklam.ca/p4p/files/nbody-seq.c>. I'll also make a git repository available if I need to make any changes. Submit your `.c` file containing the OpenCL version of the N -body code.

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. I've allocated 10 marks for effectively using workgroups.

Part 2: Far-field approximations (50 points)

Algorithmic improvements are quite 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

*fixed sizes

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

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

quadtrees or octrees to store, and thus find, the closest points³). 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` 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

³For a very readable summary of the Barnes-Hut algorithm, see <http://arborjs.org/docs/barnes-hut>.

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. For part 2, write about your design choices and results (about half a page), and hand that in along with your OpenCL code.