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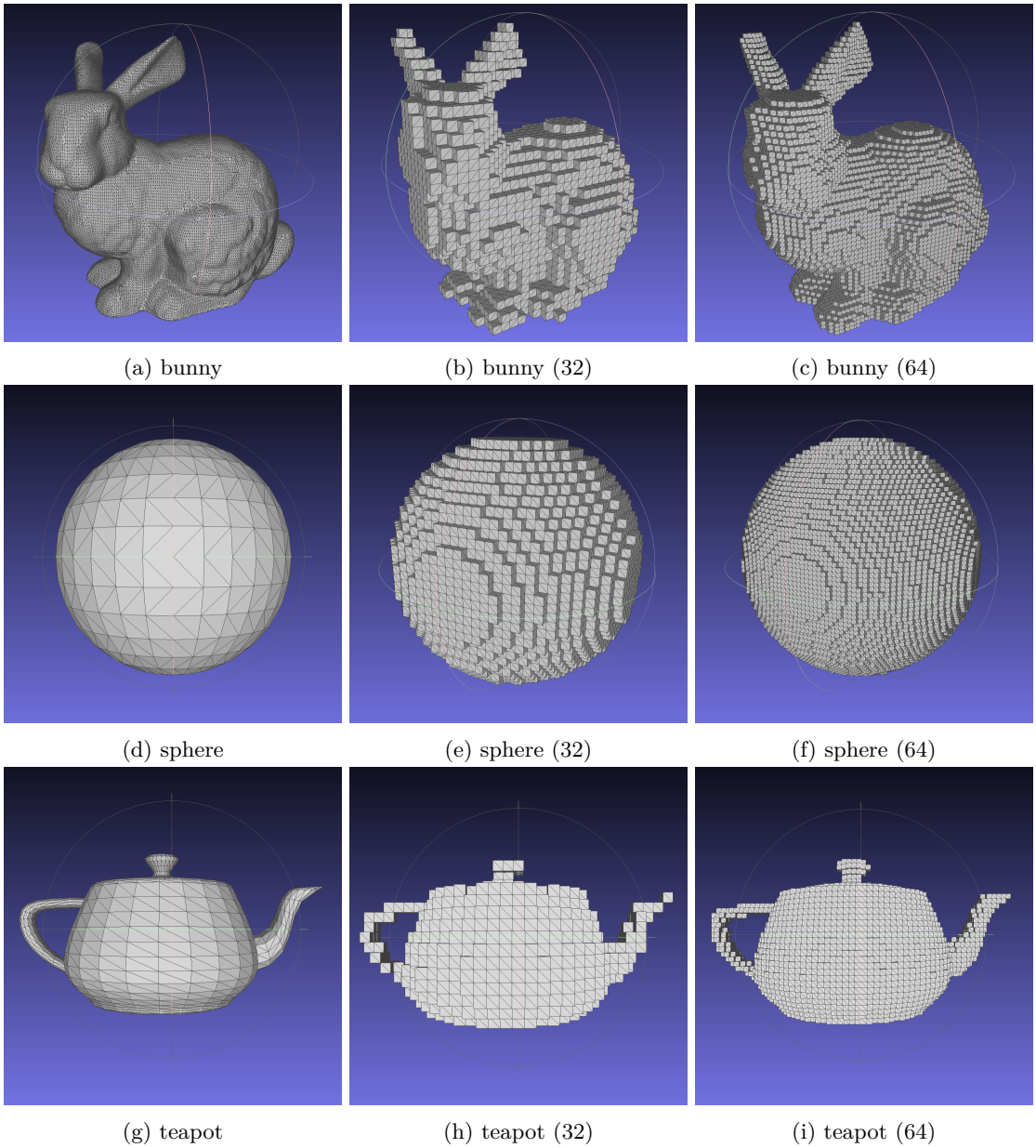
ASSIGNMENT 1 — Voxelization

1 Images of Objects



(a) bunny (b) bunny (32) (c) bunny (64)

(d) sphere (e) sphere (32) (f) sphere (64)

(g) teapot (h) teapot (32) (i) teapot (64)

Figure 1: Voxelization

2 References

I was reading on "How to check if ray intersects a triangle" and I found one article from 1997: `Fast, Minimum Storage Ray/Triangle Intersection` by Moller, T. and Trumbore, B., which provides C implementation to check ray-triangle intersection with face culling and non-culling method. I modified and added some conditions to make it applicable to the C++ voxelizer.

3 Source Code Sample

```
void intersect_tri_2(CompFab::Ray &ray, CompFab::Triangle &triangle,
                     int &out, double &t, double &u, double &v) {
    // Called by int rayTriangleIntersection(CompFab::Ray &ray,
    //                                       CompFab::Triangle &triangle);
    //
    // From https://www.graphics.cornell.edu/pubs/1997/MT97.pdf
    // Two-sided face (with two direction option)
    CompFab::Vec3 E1, E2, T, P, Q;
    double det, inv_det;

    out = 0;

    E1 = triangle.m_v2 - triangle.m_v1;
    E2 = triangle.m_v3 - triangle.m_v1;

    P = ray.m_direction % E2;

    det = E1 * P;

    if (det > -EPSILON && det < EPSILON)
        return;

    inv_det = 1.0 / det;

    T = ray.m_origin - triangle.m_v1;

    u = (T * P) * inv_det;
    if (u < 0.0 || u > 1.0)
        return;

    Q = T % E1;

    v = (ray.m_direction * Q) * inv_det;
    if (v < 0.0 || u + v > 1.0)
        return;

    t = (E2 * Q) * inv_det;

    // Comment out for bidirectional ray
    if (t < 0)
        return;
    // End comment

    out = 1;
}
```

4 Extra Credits

I did extra credits #2 (multi-ray casting) as do-able in this timeframe. I used cumulative bitwise OR to decide whether the voxel is inside or outside the boundary, which I think is naive and prone to errors as I have experimented so far. Here's some of the snippets from the source code involving multi-ray casting option.

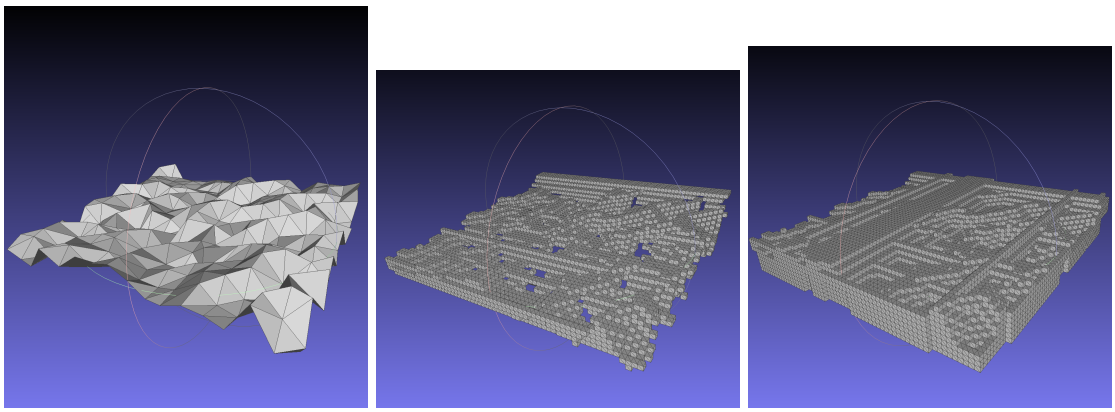
```
int main(...) {
    ...
    CompFab::Vec3 directions[3] = {
            {1., 0., 0.},
            {0., 1., 0.},
            {0., 0., 1.},
    };
    ...
    for (CompFab::Vec3 &direction: directions) {
        ...  // Iterating over each voxel
        {{{
            ...
            num_hits = numSurfaceIntersections(voxelPos, direction);
            (g_voxelGrid->m_insideArray)[k * (nx * ny) + j * ny + i] |= (num_hits % 2);
        }}}
    }
}
```

In this particular example, I used orthonormal basis (in this case, standard basis): $\{\hat{e}_X, \hat{e}_Y, \hat{e}_Z\}$
I attempted to utilize GPU acceleration via NVIDIA CUDA. I also attempted to implement OpenVDB structure into the program, but there was a lot lot of work to be done.

5 Known Problems

I did not have problems for most parts, but the obvious problem was the program is very slow as number of meshes, number of rays, and grid resolution increase (Overall knr^3). As I was doing one of the extra credits (multi-direction ray test), I used a hollow cylinder model (generated in OpenSCAD) as an input model and I saw artifacts in the output voxelized object. There are also more artifacts present in multi-ray version than uni-ray version. I suspected there were flaws in the multi-ray casting checking logic (cumulative bitwise OR).

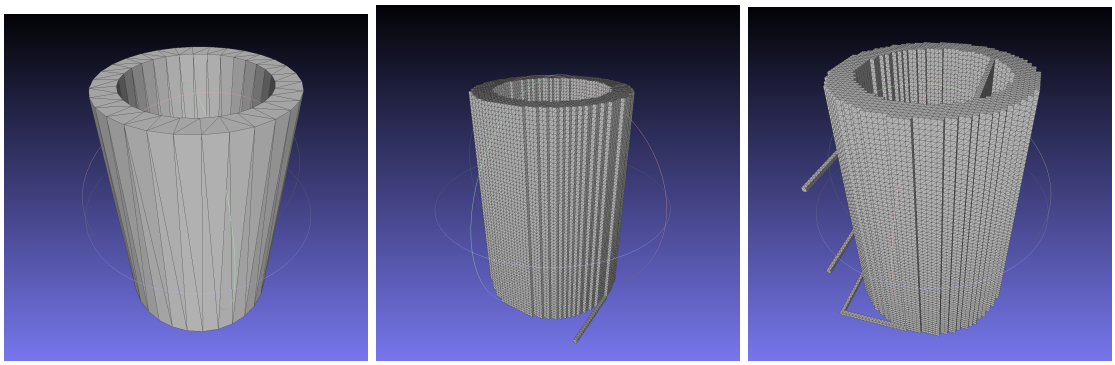
For `crumbled` model, which is a non-closed mesh object with no convex boundary to it, the multi-ray version makes it particularly solid, but that might not exactly be the goal.



(a) crumbled (b) crumbled (uni 64) (c) crumbled (multi 64)

Figure 2: Uni-ray vs Multi-ray: Crumbled

For `hollow` model, which is a closed mesh object with hole in the middle, there are some artifacts on it. At first, I thought it was the defect from the model file itself, but as I tested more, it might be from the ray casting checking algorithm. Nevertheless, overall results look promising.



(a) hollow (b) hollow (uni 64) (c) hollow (multi 64)

Figure 3: Uni-ray vs Multi-ray: Hollow

If I had more time, I would restudy the multi-ray casting logic and re-implement it in the more correct way.

6 Executable

I have modified parameters for the executable so that it can be tested easily with scripts without recompilation.

```
Usage: voxelizer <input_mesh_file> <output_mesh_file> <resolution> <multidirection?>
<input_mesh_file>       Input mesh file name
<output_mesh_file>      Output mesh file name
<resolution>            Voxelizer grid resolution, e.g., 16, 32, 64
<multidirection?>       0 for uni-directional ray casting
                        1 for tri-directional ray casting
```

Submitted by Vivatsathorn Thitasirivit on January 30, 2024.