A Novel Discretization and Numerical Solver for Non-Fourier Diffusion

Description

This is the opensource code for SIGGRAPH Asia 2020 submission:

We introduce a generalized constitutive model for diffusion-driven problems with several attractive properties:

- It fundamentally explains diffusion from the perspective of the Boltzmann Transport Equation
- It can address the issue of infinite propagation speed for diffusion, an assumption made by the widely employed Fick's/Fourier's law.
- It can capture some of the most characteristic, yet unprecedented, visual aspects of diffusion-driven physics.

In the algorithm, we propose a novel semi-implicit discretization for this diffusion model on staggered MACgrids and design a geometric Multigrid-preconditioned Conjugate Gradients solver for efficient numerical solution.

Compilation

The following instruction is tested on Ubuntu 18.04 LTS with g++7.5

Dependencies

Install Nova library and OpenGL viewer

The Nova library can be downloaded from GitHub using the following command:

```
git clone https://github.com/OrionQuest/Nova.git
```

Example projects that use the Nova core library live in a separate repository, and can be downloaded using the following commands:

```
cd Nova/Projects
git clone https://github.com/OrionQuest/Nova_Examples.git
```

Nova depends on several libraries such as GLM,FreeType,GLFW,GLEW,Boost,Assimp, etc. Run the following command to install all the dependencies:

```
sudo apt-get install libboost1.62-dev libboost-program-options1.62-dev
libboost-filesystem1.62-dev libboost-regex1.62-dev libglfw3-dev libglew-dev
libglm-dev libassimp-dev libfreetype6-dev
```

The build system uses cmake (version 3.0 or higher). We recommend the use of the graphical version ccmake for easy configuration of the environment variables. The best way to install the latest version of cmake and ccmake is to first run the following command:

```
sudo apt-get install cmake
sudo apt-get install cmake-qt-gui
sudo apt-get install libncurses5-dev
```

Extract Project

Extract non_ficks_diffusion.zip to Nova/Projects. The partial directory should look like this:

```
.
+-- Projects
|   +-- non_ficks_diffusion
|   +-- Nova_Examples
|   +-- CMakeLists.txt
...
```

Build

Run the following commands in order:

```
cd Nova
mkdir build
cd build
ccmake ..
```

Set `CMAKE_BUILD_TYPE` to `Release`, and turn `OFF` the following flags: `ENABLE_OPENIMAGEIO_PLUGIN`, `ENABLE_SOIL_PLUGIN`, `ENABLE_VARIATIONAL_FLUIDS`, `USE_C11_REGEX`, `USE_DOUBLES`.Turn all the other flags `ON`. Press `c` to configure, and then `g` to generate the `Makefile`. Finally, run the following command:

```
make -j 8
```

Configure OpenGL

Run the following commands in order:

```
cd build/
ln -s ../Projects/Nova_Examples/opengl/example/nova.conf .
```

```
ln -s ../Projects/Nova_Examples/opengl/example/fonts/ .
ln -s ../Projects/Nova_Examples/opengl/plugins/Grid/shaders/ .
```

Modify the configuration file nova.conf in *Nova/build/*

For hydrogel visualization

```
...
#Plugin=libplugin_Embedded_Deformables
Plugin=libplugin_Non_Ficks_Diffusion
#Plugin=libplugin_Autonomous_Navigation
...
```

For other simulations

```
...
#Plugin=libplugin_Embedded_Deformables
#Plugin=libplugin_Non_Ficks_Diffusion
Plugin=libplugin_Autonomous_Navigation
...
```

Demos

Smoke

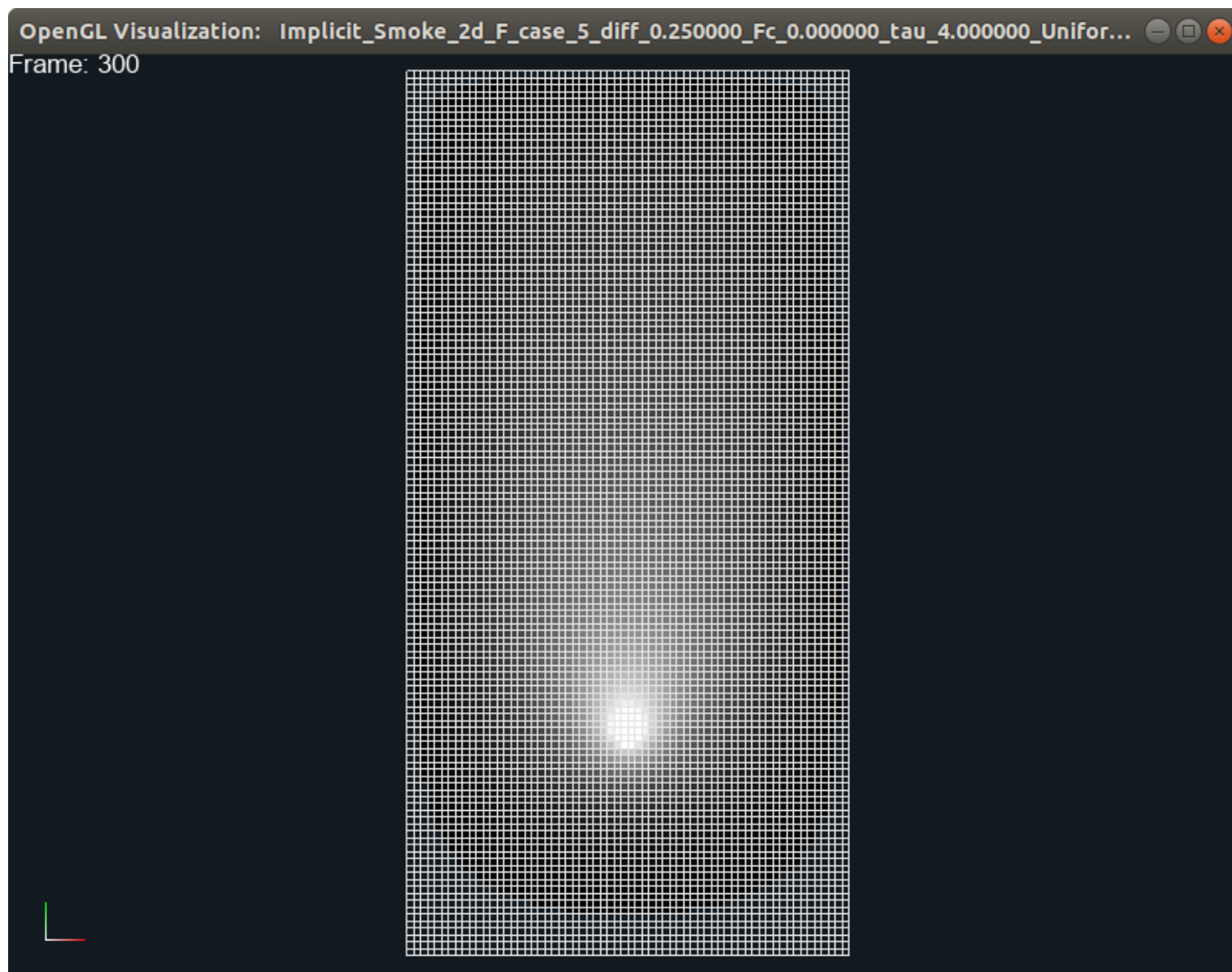### With Fourier Diffusion

Go to the build directory (*Nova/build/*), run the following command for Fourier diffusion test case:

```
./bin/smoke_3d -threads 8 -last_frame 500 -test_number 3 -diff_coeff 0.01 -
bv 1 -sr 50 -size 256 512 256 -mg_levels 4 -ficks
```

Use opengl viewer to check out the result, the diffusive smoke:

```
./bin/opengl
Implicit_Smoke_2d_F_case_5_diff_0.250000_Fc_0.000000_tau_4.000000_Uniform_b
v_0.500000_sr_50.000000_Resolution_64x128/
```
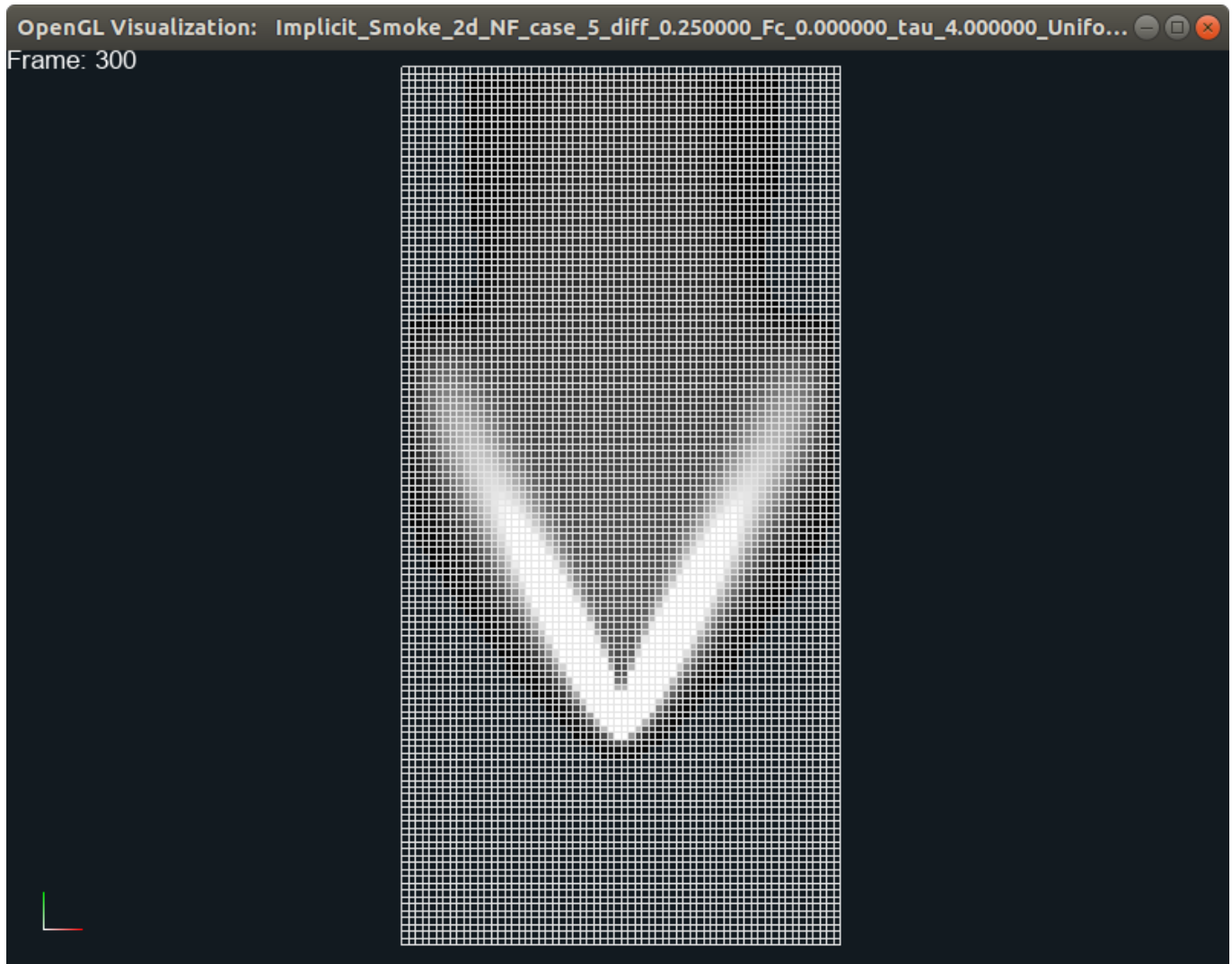
With Non-Fourier Diffusion

Go to the build directory (*Nova/build/*), run the following command for non-Fourier diffusion test case:

```
./bin/smoke_2d -threads 8 -last_frame 300 -diff_coeff 0.25 -fc 0 -tau 4 -bv
0.5 -sr 50  -size 64 128 -mg_levels 2 -test_number 5
```

Use opengl viewer to check out the cone structure:

```
./bin/opengl
Implicit_Smoke_2d_NF_case_5_diff_0.250000_Fc_0.000000_tau_4.000000_Uniform_
bv_0.500000_sr_50.000000_Resolution_64x128/
```
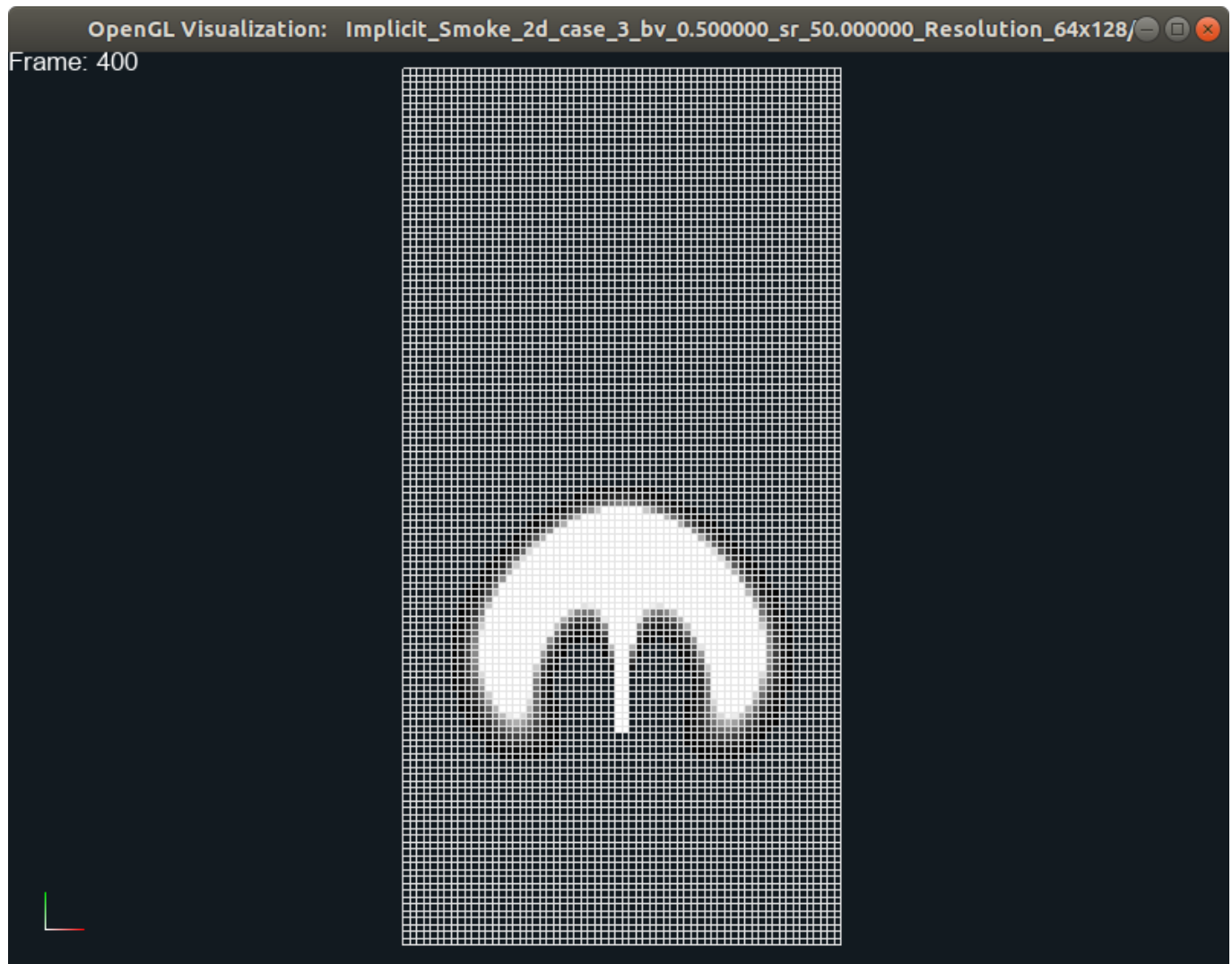
Without Diffusion

Go to the build directory (*Nova/build/*), run the following command for smoke simulation without any diffusion:

```
./bin/smoke_3d -threads 8 -last_frame 500 -test_number 3 -bv 1 -sr 50 -size
256 512 256 -mg_levels 4 -nd
```

Use opengl viewer to check out the result:

```
./bin/opengl
Implicit_Smoke_2d_case_3_bv_0.500000_sr_50.000000_Resolution_64x128/
```

Here are some of the command options:

- diff_coeff: the diffusion coeffient
- bv: background velocity. The velocity field is set to be along y-axis
- sr: source rate, the speed that we add source to the source region
- size: whole domain size
- mg_levels: multigrid levels
- ...

Snowflake

Go to the build directory (*Nova/build/*), run commands for different test cases as below:

With Fourier Diffusion

```
  ./bin/snow_flake_2d -threads 8 -last_frame 200 -framerate 240 -omega 6 -
  taus 3e-4 -gamma 10 -K 2 -delta 1e-2 -eps_xy 1e-2 -ma 0.9 -SR 0 -rf 5e-2 -
  dt 1e-4 -size 256 256 -cw 3e-2  -ficks -ed
```

During simulation, you can go to the build directory(*Nova/build/*), and run the following command to view the result:

```
./bin/opengl Snow_Flake_F_2d_case1_6branches_Resolution_256x256/
```
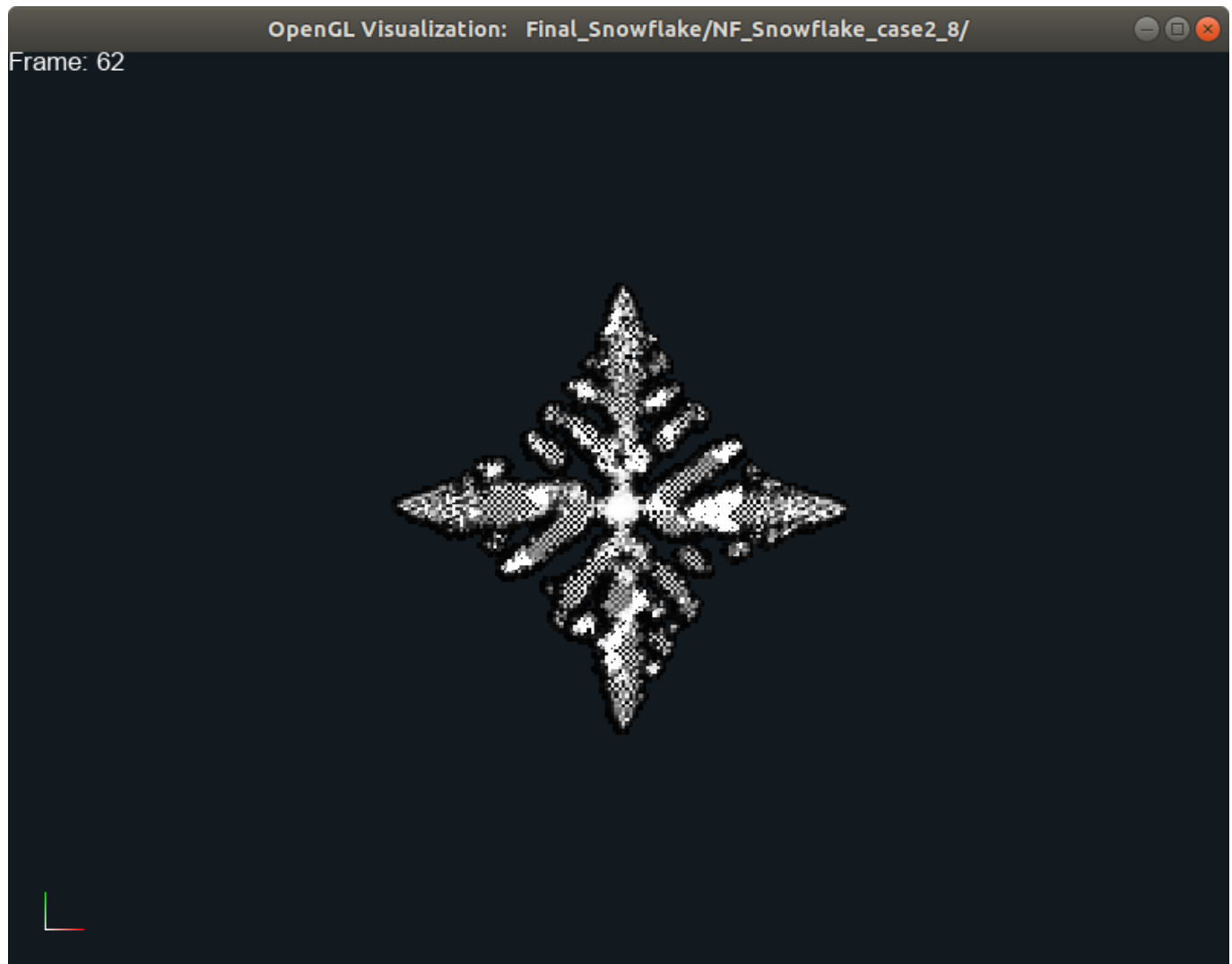

With Non-Fourier Diffusion

```
./bin/snow_flake_2d -threads 8 -last_frame 120 -framerate 480 -omega 8 -
taus 1e-5 -tau1 1e-2 -tau2 1e-4 -fc1 0 -fc2 0 -gamma 10 -K 5 -delta 1e-2 -
eps_xy 1e-2 -ma 0.9 -rf 5e-2 -dt 1e-6 -size 256 256  -ed
```

During simulation, you can go to the build directory(*Nova/build/*), and run the following command to view the result:

```
./bin/opengl Snow_Flake_NF_2d_case1_8branches_Resolution_256x256/
```

Coral Reef

Go to the build directory (*Nova/build/*), run the following command

```
./bin/dendrite_growth_3d -threads 8 -last_frame 500 -ficks -ed -framerate
240 -taus 3e-4 -gamma 10 -K 4 -delta 1e-2 -eps 1e-2 -ma 0.9 -rf 5e-2 -dt
1e-4 -size 120 200 120 -cw 3e-2
```

Hydrogel Dwelling

Go to the build directory (*Nova/build/*), run the following command

```
./bin/nfd_3d -test_number 1 -last_frame 10 -threads 8 -E 40 -nu 0.4 -
diff_coeff 0.01 -eta 10 -fc 0 -tau 1 -size 512 512 512 -mg_levels 5 -n_s
400000 -min_dt 1e-6 -max_dt 1e-3 -nbw 3
```