CUDA Parallel Programming
Homework 8

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1 Source codes

1.1 File Layout

- Ising2D_NGPU/ising2d_ngpu_gmem_v2.cu - Main code computes the GPU accelerated Monte Carlo simulation of 2D ising model on a torus.
- Makefile - Script to auto generate executable from code.
- Ising2D_NGPU/experiment.sh - Script to auto generate results of the GPU accelerated Monte Carlo simulation of 2D ising model on a torus. It test different block size setup on both 1GPU case and 2GPU case in simulation, and record their statistical result.
- Ising2D_NGPU/experiment_1.sh - Script to auto generate results of the GPU accelerated Monte Carlo simulation of 2D ising model on a torus. It test different temperature setup on both 1GPU case and 2GPU case in simulation using optimal block size get from experiment.sh, and record their statistical result.
- Ising2D_NGPU/result/GPU_* - Generated result using differeng GPU amount, the number behind "GPU" is the gpu amount I assigned to perform the experiment

- Ising2D_NGPU/result/GPU_*/block_*/ - Generated result using differeng block size, the number behind "block" is the block size I assigned to perform the experiment.
- Ising2D_NGPU/result/GPU_*/T_*/ - Generated result using differeng temperature, the number behind "T" is the temperature I assigned to perform the experiment.
- Ising2D_NGPU/result/GPU_*/block_*/Output - Output the energy and magnetization density in every 100 sweeps.
- Ising2D_NGPU/result/GPU_*/block_*/Output_2 - Output $\langle E \rangle$, δE, $\langle M \rangle$, δM after applying autocorrelation function.
- Ising2D_NGPU/result/GPU_*/block_*/ising2d_ngpu_gmem.dat - Output the energy and magnetization density in every 10 sweeps.
- Ising2D_NGPU/result/GPU_*/block_*/spin_ngpu_gmem.dat - Output the final spin in each cell density.
- Ising2D_NGPU/auto_correlation/autoT_B.c - The program to calculate the $\langle E \rangle$ and $\langle M \rangle$ and their δE, δM after applying auto-correlation on them.
- notebook/*.png - Plots concluding output result

1.2 Usage

Make code in both Ising2D_NGPU/ directory Run the experiment.sh and experiment_1.sh script in Ising2D_NGPU/ directory

```
cd Ising2D_NGPU
make
sh experiment.sh
sh experiment_1.sh
```

And it will produce the simulation result with different GPU amount, block size, and temperature.

2 Code design

In this assignment, I adopted the grid division technique learned in "solving laplacian equation in multi-GPU" to apply on this assignment. Firstly, I made the logic border of multi-GPU to be connected to its neighbor GPU using "enable peer access" in CUDA runtime library, and then use openMP to handle each GPU's execution and use "barrier" to synchronize their work, which prevent them from destroying the checkerboard scheme.

There are two conditions that will break the checkerboard scheme, the first one is "Neighbor of current GPU and current GPU are running 'even' or 'odd' checkerboard scheme while the lattice dimension of them aren't even", this will cause the GPU to reference the changed spin of their neighbor. For this problem I simply prevent it assigning the lattice size that will cause this problem.

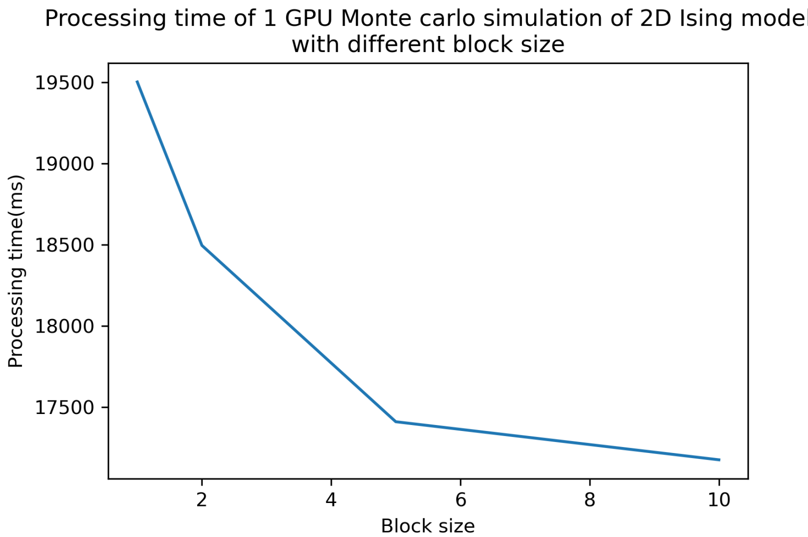
The second one is "The synchornization problem", which means one GPU is running 'even' checkerboard scheme, while the other GPU already finished the 'even' checkerboard scheme and start running 'odd' checkerboard scheme, this will cause the GPU to reference the changed spin of their neighbor problem, too. For this problem I simply insert the openMP barrier to prevent them from running different scheme simultaneously.

3 Result

3.1 Experiment environment

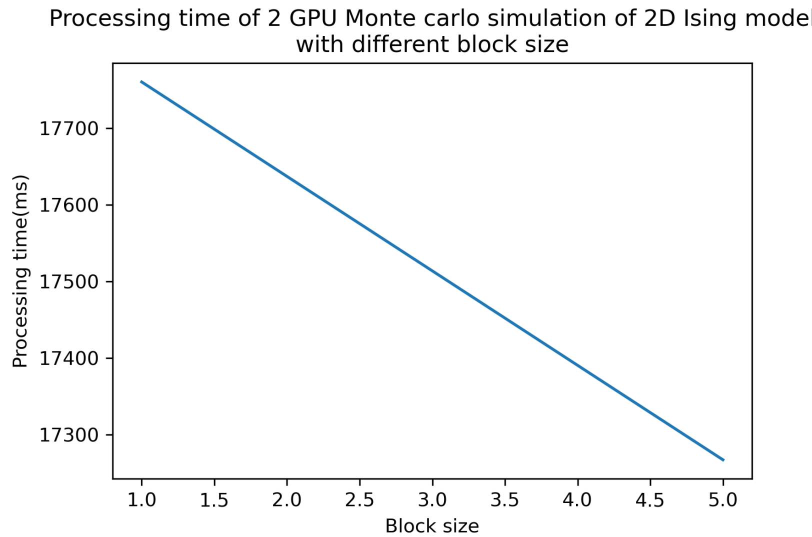
I ran my code on workstation provided in course, below is the Setup of workstation

- Operating system: Linux version 4.19.172 (root@twcp1) (gcc version 6.3.0 20170516 (Debian 6.3.0-18+deb9u1))
- CPU: Intel(R) Core(TM) i7-4790 CPU @ 3.60GHz
- GPU: Nvidia GTX 1060 6GB
- Memory: 32GB



3.2 Performance

Below two figures showed 1 GPU and 2 GPU processing time of monte carlo simulation of 2D ising model on the torus using different block size.

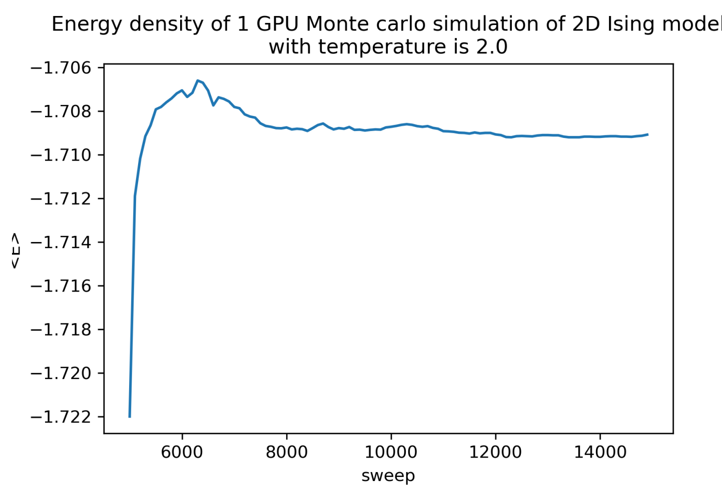


3.3 Result plot

3.3.1 1 GPU

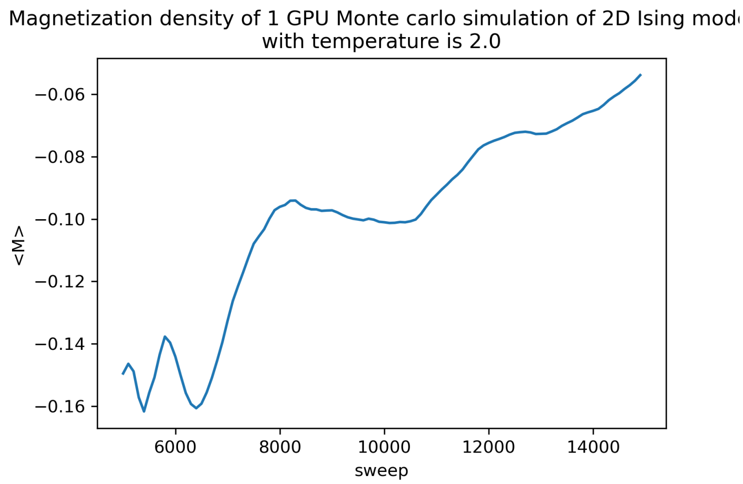
Below two figures show the energy density and magnetization density using temperature=2.0

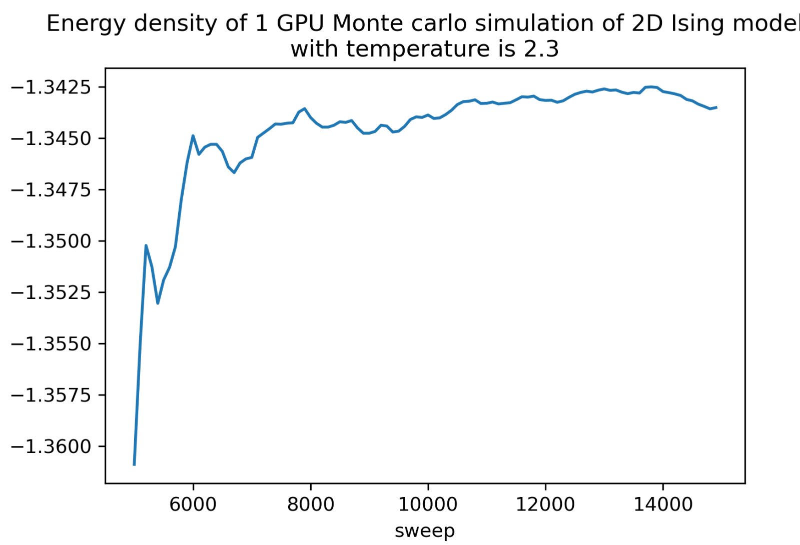
Their $\langle E \rangle = -1.708829e+000 \pm 2.717343e-004$, $\langle M \rangle = -9.958487e-002 \pm 2.325785e-002$



Below two figures show the energy density and magnetization density using temperature=2.3

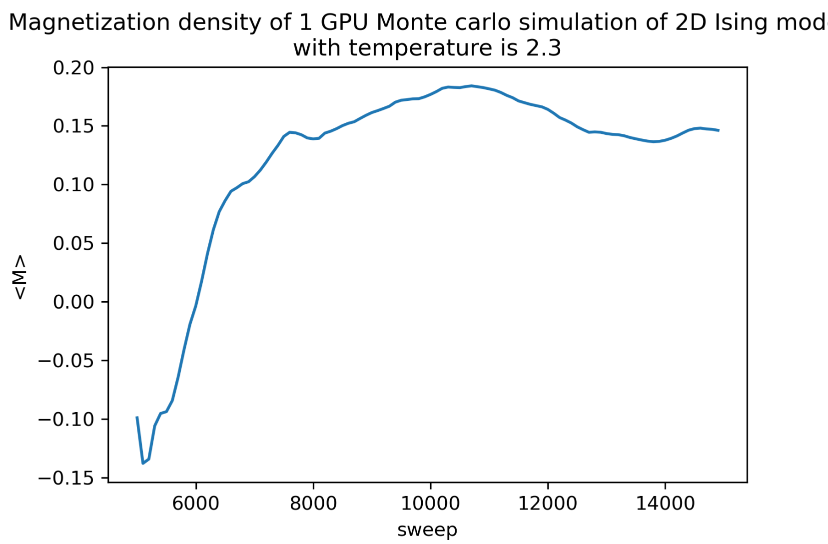
Their $\langle E \rangle = -1.344627e + 000 \pm 1.485984e - 003$, $\langle M \rangle = 1.220034e - 001 \pm 3.549629e - 002$

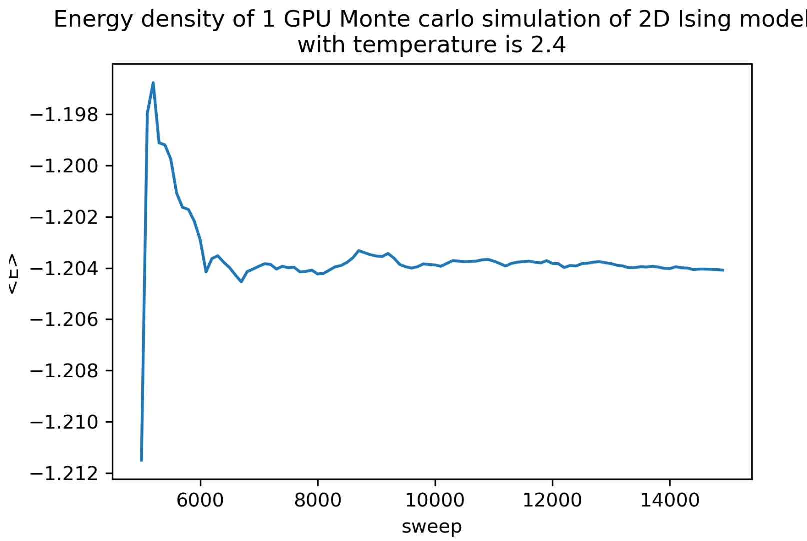




Below two figures show the energy density and magnetization density using temperature=2.4

Their $\langle E \rangle = -1.203588e+000 \pm 2.851766e-004$, $\langle M \rangle = -1.539886e-002 \pm 3.005923e-003$



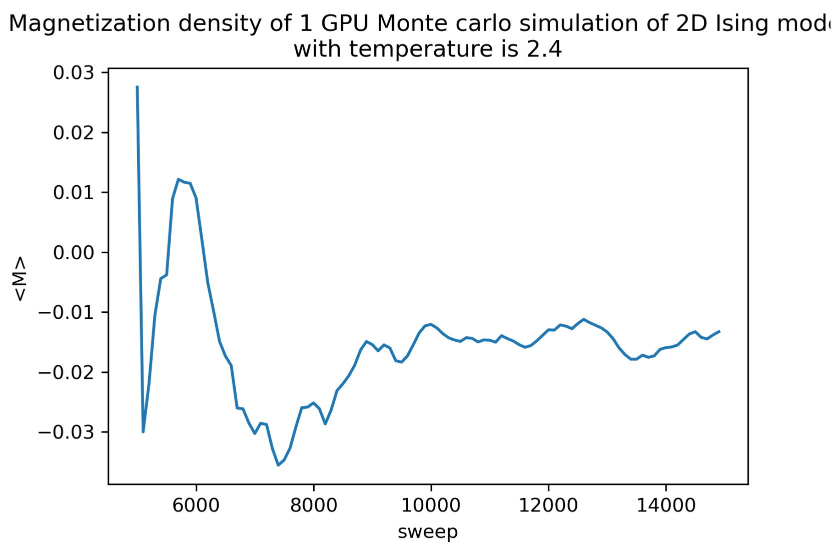


The other simulation figures using different temperature can be found in notebook/ directory, which format is 1gpu_⟨temperature⟩_[E][M], where "E" and "M" indicate the figure showing the energy density of magnetization density.

3.3.2 2 GPU

Below two figures show the energy density and magnetization density using temperature=2.1

Their $\langle E \rangle = -1.661916e+000 \pm 3.137847e-004$, $\langle M \rangle = -8.686338e-001 \pm 1.927622e-004$



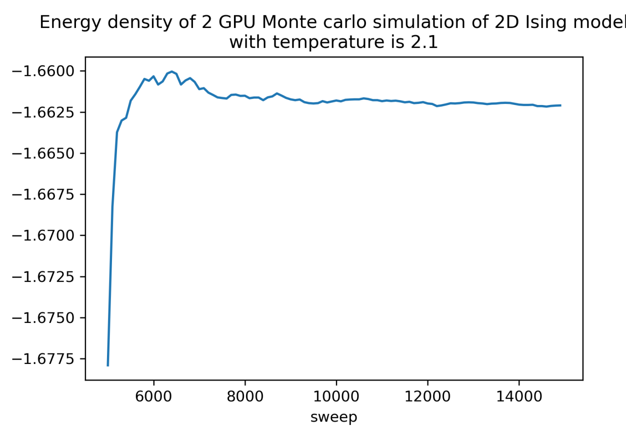
Below two figures show the energy density and magnetization density using temperature=2.2

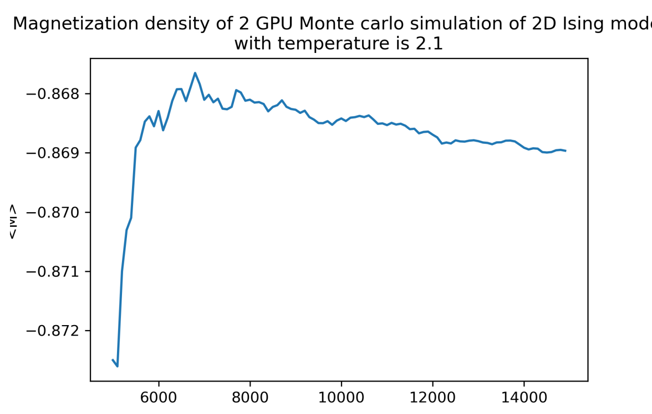
Their $\langle E \rangle = -1.545266e+000 \pm 7.267663e-004$, $\langle M \rangle = -7.833565e-001 \pm 1.346352e-003$

Below two figures show the energy density and magnetization density using temperature=2.5

Their $\langle E \rangle = -1.105536e+000 \pm 7.271165e-004$, $\langle M \rangle = 3.581217e-003 \pm 1.653809e-003$

The other simulation figures using different temperature can be found in notebook/ directory, which format is 2gpu_⟨temperature⟩_[E][M], where "E" and "M" indicate the figure showing the energy density of magnetization density.

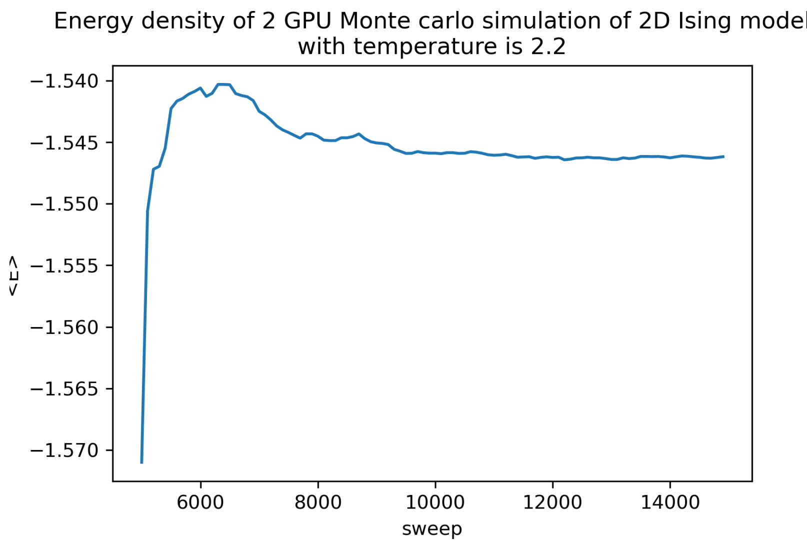


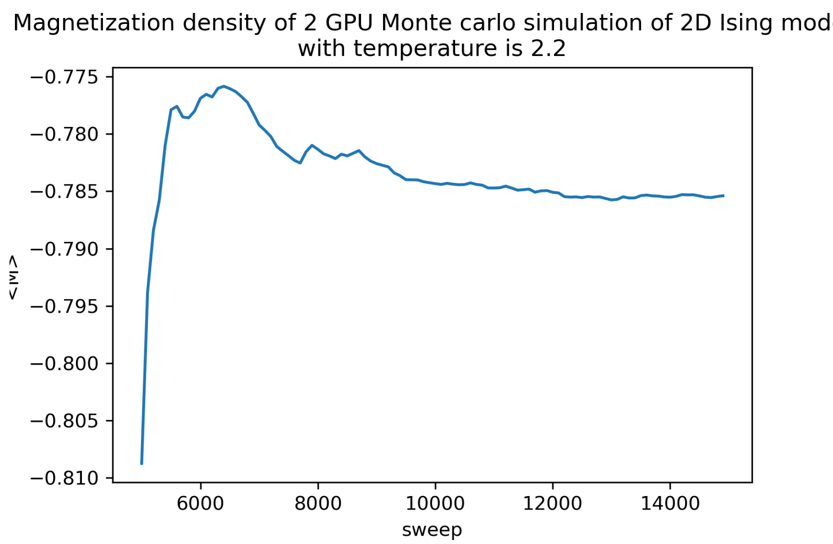


Below figure shows absolute magnetization over different temperature.

3.4 Observation

The 2 GPU case is faster than 1 GPU case of monte carlo simulation of 2D ising model on the torus in all of the plausible block size 2 GPU case can use, but due to the checkerboard scheme's limitation, I can't test more

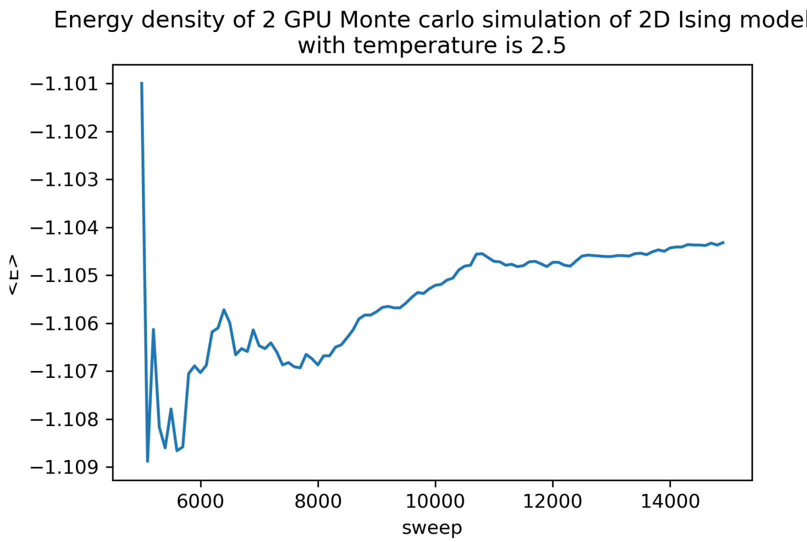


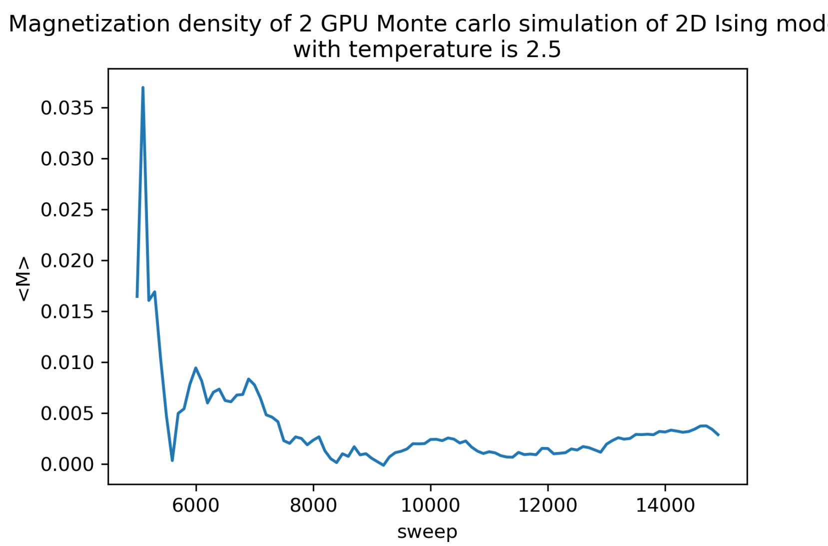


block size to get more accurate data on other block size setup for 2 GPU case.

From the figure shown above, we can see that after long time(sweeps) both the energy density and magnetization density gets stable eventually.

The absolute magnetization over different temperature figure approximately agree with Onsager's solution with no applied external magnetic





field.

4 Reference

Numerical Analysis of 2-D Ising Model

Classical Monte Carlo and the Metropolis Algorithm: Revisiting the 2D Ising Model