CUDA 2025 HW5

Heat Diffusion on a Square Plate

Problem Statement

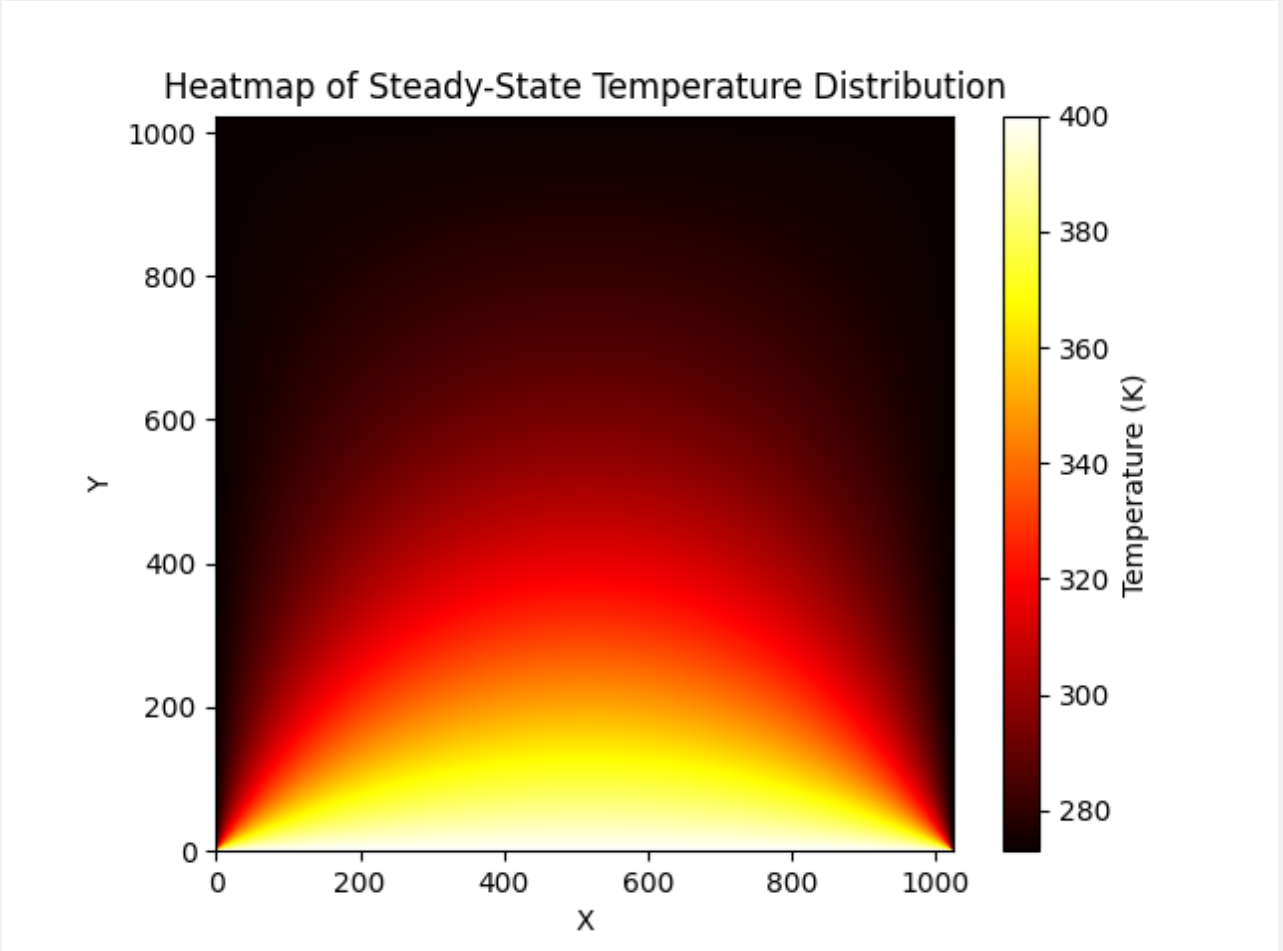
We solve the **thermal equilibrium temperature distribution** on a 1024×1024 square plate using CUDA. The temperature on the **top edge** is fixed at **400 K**, and the remaining three edges are fixed at **273 K**. The problem is governed by the steady-state **2D Laplace equation**:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0$$

We implement this using **Jacobi iteration (ω = 1)** on both **single-GPU** and **multi-GPU** configurations to evaluate performance and determine the optimal `threadsPerBlock`.

Result Summary

Heatmap generated with iter = 1000000



Timing Table

Configuration	Threads Per Block	Time / Iteration (ms)	Speedup (vs CPU)

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CPU	–	6.799	1.0×
Single-GPU	4×4	0.085	79.8×
Single-GPU	8×8	0.029	234.4×
Single-GPU	**16×16**	**0.023**	**295.6×**
Single-GPU	32×32	0.024	283.3×
Multi-GPU (2x)	4×4	0.063	107.9×
Multi-GPU (2x)	8×8	0.033	206.0×
Multi-GPU (2x)	**16×16**	**0.025**	**271.9×**
Multi-GPU (2x)	32×32	0.026	261.5×

Trend Observations

1. **Block Size Optimization**:
    - Performance improves as block size increases, with optimal values at **16×16**.
    - Beyond this, gains diminish or slightly reverse due to shared memory or occupancy limits.
2. **Single vs Multi-GPU**:
    - Multi-GPU performance improves over single-GPU only at smaller block sizes.
    - Best performance for both setups is at `threadsPerBlock = 16×16`.
3. **Accuracy**:
    - All GPU results are **numerically identical to the CPU baseline**, validating correctness.

Conclusion

- The **fastest configuration** is `single_T16` at **0.023 ms/iteration**, achieving ~296× speedup.
- Multi-GPU achieves nearly the same best-case speedup, showing good scaling.
- Optimal block size is **16×16**, which balances parallelism and memory efficiency.

Environment

- OS: Ubuntu 22.04.3 LTS
- CPU: Intel(R) Core(TM) i7-9800X CPU @ 3.80GHz
- GPU: NVIDIA GeForce RTX 2080 Ti ×2
- CUDA Version: 12.1
- Grid Size: 1024 × 1024
- Iterations: 10,000

Usage Instructions

1. Source Files

- CPU Baseline: `hw5_cpu.c`
- CUDA Kernels: `hw5_single.cu`, `hw5_multi.cu`
- Driver Script: `driver.py`

2. Compile

```
gcc hw5_cpu.c -o hw5_cpu
nvcc hw5_single.cu -o hw5_single
nvcc hw5_multi.cu -o hw5_multi
```

3. Run

```
python3 driver.py 10000
```

This script automatically benchmarks various block sizes and compares single-GPU and multi-GPU performance.
