TedyxEngine – A 2D Thermodynamics simulator

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https://github.com/Exynos9820/ThedyxEngine

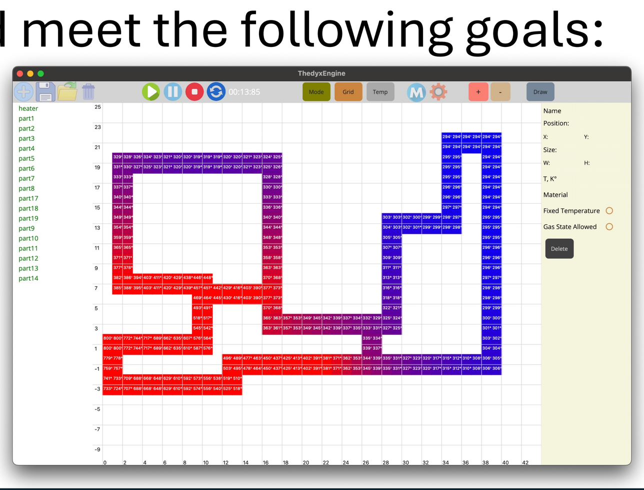
Introduction

Thermodynamics is a fundamental branch of physics that describes heat transfer and energy conversion processes. However, traditional teaching methods and theoretical models often fail to provide an intuitive grasp of how heat propagates in different real-world materials. To address this challenge, **ThedyxEngine** has been developed as a **2D physics-based simulation** that visualizes heat transfer in real-time. By incorporating conduction, convection, and radiation, the engine offers an interactive way to explore thermodynamics.

Goals

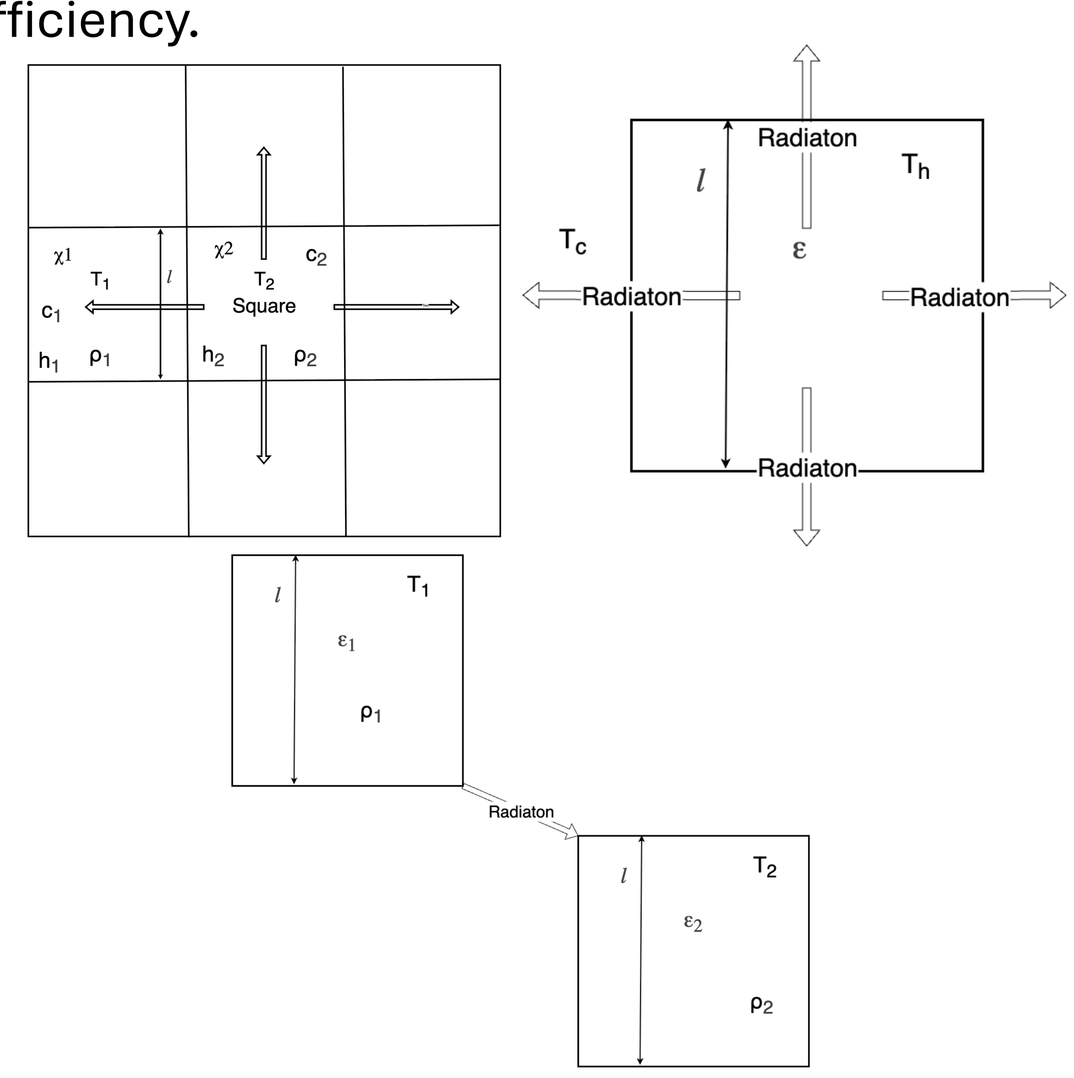
ThedyxEngine should meet the following goals:

- User-Friendly
- Cross-Platform
- High performance
- Be open source
- Visual intuitive
- Accurate



Methodology

ThedyxEngine employs the **Finite Difference Method (FDM)** to simulate heat transfer with high accuracy. By discretizing objects into a grid of small squares, the engine applies numerical methods to approximate heat diffusion over time and this approach allows for precise calculations, while maintaining computational efficiency.



The simulation operates in discrete time steps, calculating the amount of energy transferred in each interval for convection, conduction and radiation. This step-by-step approach ensures a smooth and incremental temperature changes, making it possible to visualize thermal dynamics in real time.

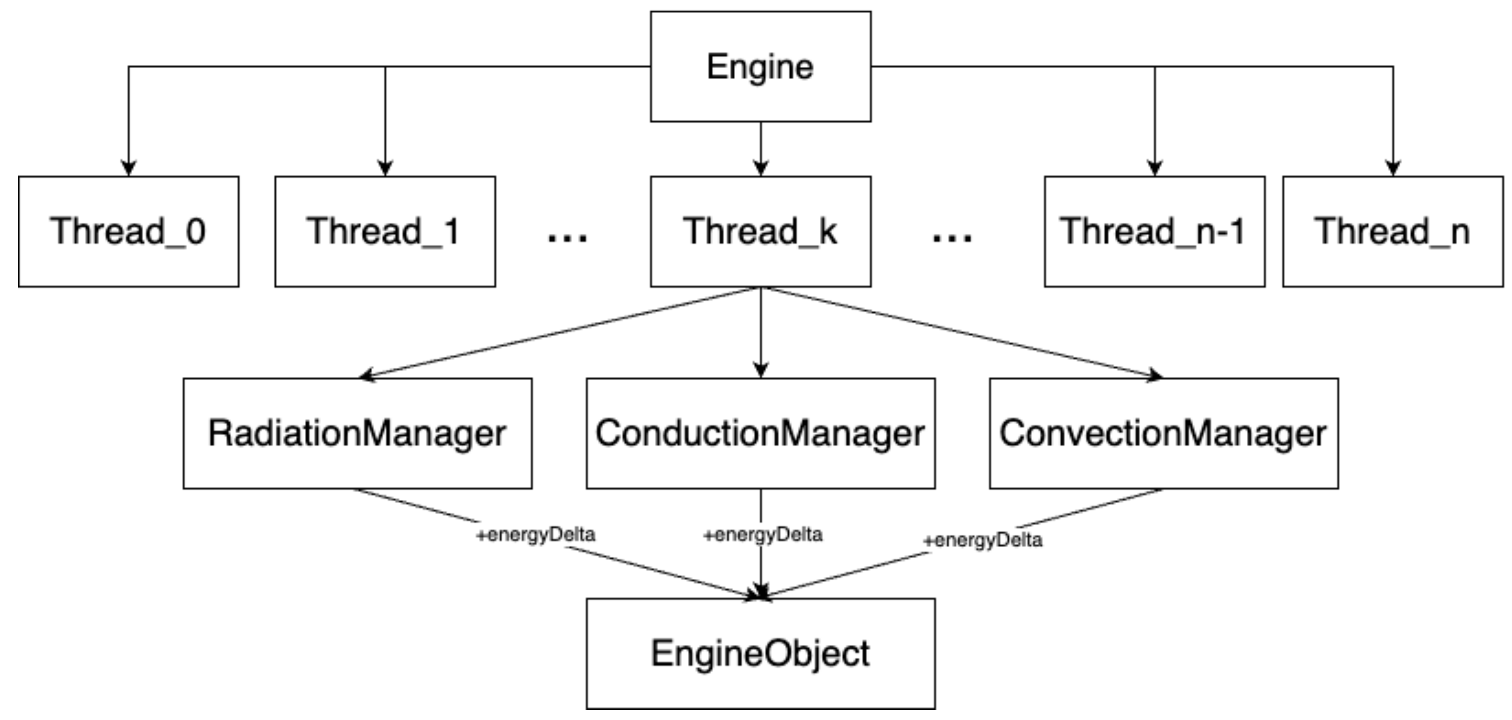
We optimize performance by precomputing adjacent squares for convection and conduction, reducing complexity from $O(n^2)$ to $O(n)$. For radiation, a precomputed visibility map ensures energy transfer calculations only consider visible squares, reducing complexity from $O(n^3)$ to $O(nm)$, where m is the search depth. These optimizations, enhance engine efficiency and leverage performance for faster simulations.

Dedication

I would like to express my deepest gratitude to Prof. Dr. techn. Alexander Wilkie for his valuable guidance, patience, help, and encouragement throughout the development of this thesis.

Solution Architecture

ThedyxEngine is built to efficiently simulate heat transfer across various materials, leveraging a multi-threaded architecture that takes full advantage of modern multi-core processors. By dynamically distributing tasks across multiple threads, the engine ensures that heat conduction, convection, and radiation are computed in parallel, significantly improving performance and scalability.



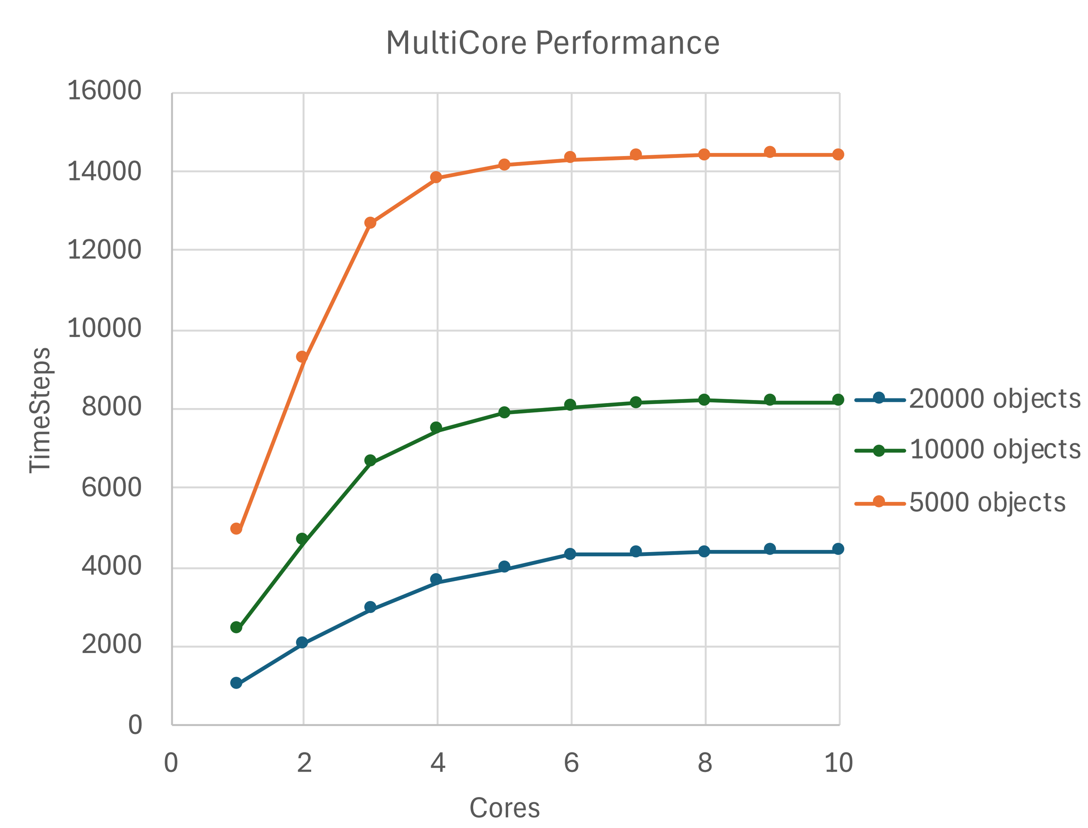
At the core of this system is the engine itself, which acts as the central coordinator. It detects available processing power and allocates resources to maintain real-time execution. Instead of processing all objects sequentially, the engine divides the workload, assigning separate threads to different parts of the simulation. Each thread independently handles a portion of the environment, calculating temperature changes and energy transfer before the results are combined into a cohesive simulation state.

To maintain both accuracy and efficiency, heat transfer is managed through specialized components that handle conduction through solid materials, convection in fluids and gases, and radiation across open spaces. By keeping these calculations separate and optimized, the engine remains highly adaptable and precise.

Benchmarking Multi-Core Efficiency

ThedyxEngine scales across multiple CPU cores when simulating heat transfer in different workloads. We measured the number of simulation timesteps computed per minute while varying the number of CPU cores.

The results show a significant speedup as more cores are utilized, with performance peaking before reaching a saturation point. Efficient workload distribution ensures well-balanced computation, preventing bottlenecks and maximizing efficiency. This optimization allows ThedyxEngine to handle complex simulations smoothly, making it well-suited for large-scale scenarios.



Precision Benchmarking

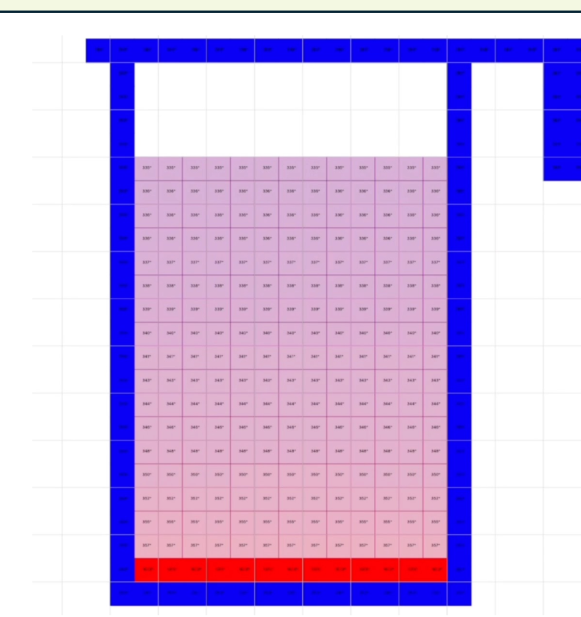
We tested ThedyxEngine by simulating the heating of a real-world smart kettle, comparing the temperature rise over time with actual data. The simulation accounted for heat transfer through conduction, convection, and radiation and was based on a real coefficients for materials and data from the real world.

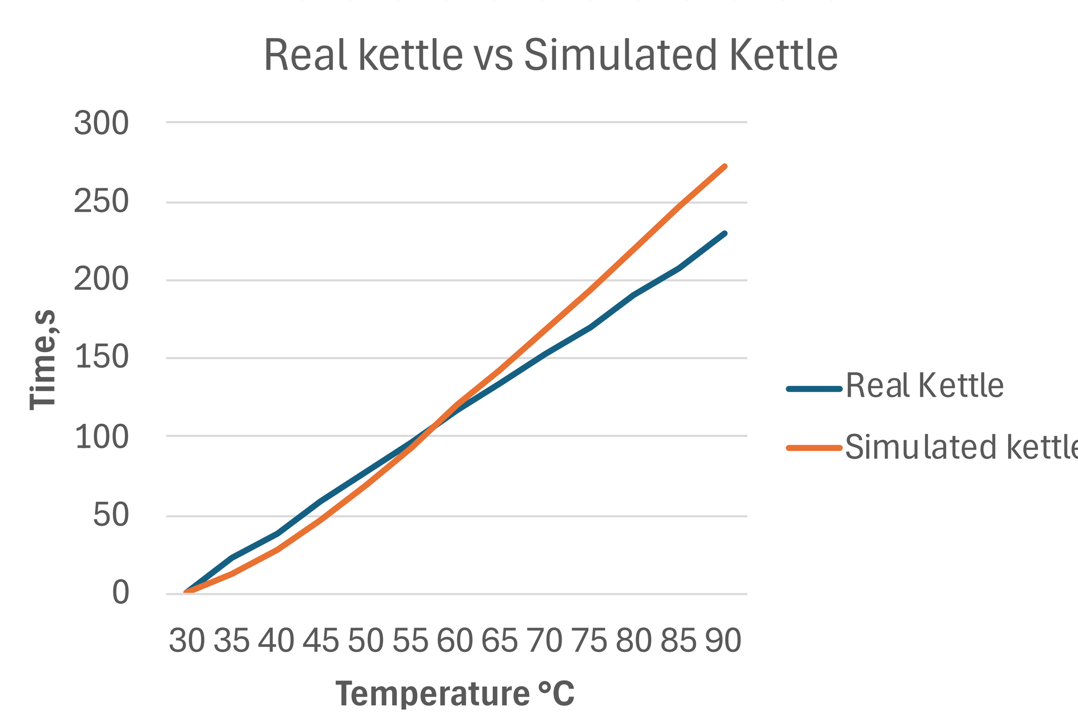
The simulation closely matched real-world data, with minor deviations:

- **Below 60°C:** The simulated kettle heats slower.
- **Above 60°C:** The simulated kettle heats faster.

These differences are due to the simulation using constant thermal properties, whereas real materials change with temperature. Future improvements could include dynamic thermal coefficients for more accurate results.

Overall, ThedyxEngine provides realistic thermal behavior, making it a valuable educational tool.





Conclusion

ThedyxEngine meets its goals by providing an intuitive tool for simulating heat transfer through conduction, convection, and radiation. It accurately models temperature changes using real-time color gradients and a grid-based system. Customizable material properties enable a wide range of simulations. Future improvements could enhance its accuracy and expand its applications in scientific and engineering fields.