

# Reinforcement Learning for Optimizing 3D Printing Paths

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The field of 3D printing, particularly in Powder Bed Fusion (PBF) processes, has unlocked new possibilities for manufacturing complex geometries and highly customized structures. However, the process is often limited by common defects such as delamination, balling, and warping, which compromise mechanical properties, surface quality, and structural integrity. Addressing these challenges traditionally involves extensive trial-and-error adjustments.

To address these limitations, we develop a data-driven framework leveraging reinforcement learning (RL) to optimize the PBF process with the goal of achieving "first-time right" prints. While RL can be employed to adjust toolpath strategies or process parameters (e.g., laser intensity), this study focuses on toolpath optimization. The framework is built on numerical simulations of the heat transfer problem in PBF, which model the thermal dynamics of a single layer of heated powder. By using simulation data directly instead of relying on reward functions based on assumptions [1,2], the framework incorporates real process physics, enabling a more generalizable and robust optimization approach. By dynamically adjusting the print path, the framework minimizes thermal gradients and defects such as overheating and uneven cooling.

The use of these numerical simulations allows us to train the RL framework in a controlled environment, avoiding the need for costly and time-intensive physical experiments. This approach not only reduces material waste but also enhances our understanding of the relationship between thermal behavior and defect formation. By simulating and analyzing the thermal dynamics, the framework identifies and adjusts the toolpath to minimize thermal gradients, leading to the discovery of an optimal path. This ensures a more reliable and efficient PBF process, improving print quality and consistency while streamlining the manufacturing workflow.

## References

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- [2] Qin M, Ding J, Qu S, Song X, Wang C.L, Liao, W. Deep reinforcement learning based toolpath generation for thermal uniformity in laser powder bed fusion process, Vol. 79, Additive Manufacturing, Elsevier B.V., 2024. DOI: 10.1016/j.addma.2023.103937.

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