

Mastering the Game of Go without Human Knowledge

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A long-standing goal of artificial intelligence is an algorithm that learns, *tabula rasa*, superhuman proficiency in challenging domains. Recently, *AlphaGo* became the first program to defeat a world champion in the game of Go. The tree search in *AlphaGo* evaluated positions and selected moves using deep neural networks. These neural networks were trained by supervised learning from human expert moves, and by reinforcement learning from self-play. Here, we introduce an algorithm based solely on reinforcement learning, without human data, guidance, or domain knowledge beyond game rules. *AlphaGo* becomes its own teacher: a neural network is trained to predict *AlphaGo*'s own move selections and also the winner of *AlphaGo*'s games. This neural network improves the strength of tree search, resulting in higher quality move selection and stronger self-play in the next iteration. Starting *tabula rasa*, our new program *AlphaGo Zero* achieved superhuman performance, winning 100-0 against the previously published, champion-defeating *AlphaGo*.

Much progress towards artificial intelligence has been made using supervised learning systems that are trained to replicate the decisions of human experts ¹⁻⁴. However, expert data is often expensive, unreliable, or simply unavailable. Even when reliable data is available it may impose a ceiling on the performance of systems trained in this manner ⁵. In contrast, reinforcement learning systems are trained from their own experience, in principle allowing them to exceed human capabilities, and to operate in domains where human expertise is lacking. Recently, there has been rapid progress towards this goal, using deep neural networks trained by reinforcement learning. These systems have outperformed humans in computer games such as Atari ^{6,7} and 3D virtual environments ⁸⁻¹⁰. However, the most challenging domains in terms of human intellect – such as the

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