

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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Table of Contents Mastering The Game Of Go Without Human Knowledge

1. Understanding the eBook Mastering The Game Of Go Without Human Knowledge
 - The Rise of Digital Reading Mastering The Game Of Go Without Human Knowledge
 - Advantages of eBooks Over Traditional Books
2. Identifying Mastering The Game Of Go Without Human Knowledge
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Mastering The Game Of Go Without Human Knowledge
 - User-Friendly Interface
4. Exploring eBook Recommendations from Mastering The Game Of Go Without Human Knowledge
 - Personalized Recommendations
 - Mastering The Game Of Go Without Human Knowledge User Reviews and Ratings
 - Mastering The Game Of Go Without Human Knowledge and Bestseller Lists
5. Accessing Mastering The Game Of Go Without Human Knowledge Free and Paid eBooks
 - Mastering The Game Of Go Without Human Knowledge Public Domain eBooks
 - Mastering The Game Of Go Without Human Knowledge eBook Subscription Services

- Mastering The Game Of Go Without Human Knowledge Budget-Friendly Options
- 6. Navigating Mastering The Game Of Go Without Human Knowledge eBook Formats
 - ePub, PDF, MOBI, and More
 - Mastering The Game Of Go Without Human Knowledge Compatibility with Devices
 - Mastering The Game Of Go Without Human Knowledge Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Mastering The Game Of Go Without Human Knowledge
 - Highlighting and Note-Taking Mastering The Game Of Go Without Human Knowledge
 - Interactive Elements Mastering The Game Of Go Without Human Knowledge
- 8. Staying Engaged with Mastering The Game Of Go Without Human Knowledge
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Mastering The Game Of Go Without Human Knowledge
- 9. Balancing eBooks and Physical Books Mastering The Game Of Go Without Human Knowledge
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Mastering The Game Of Go Without Human Knowledge
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Mastering The Game Of Go Without Human Knowledge
 - Setting Reading Goals Mastering The Game Of Go Without Human Knowledge
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Mastering The Game Of Go Without Human Knowledge
 - Fact-Checking eBook Content of Mastering The Game Of Go Without Human Knowledge
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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