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Wolfgang Ertel

Introduction to Artificial Intelligence

Second Edition

Translated by Nathanael Black
With illustrations by Florian Mast

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Preface to the Second Edition

After 60 years, Artificial Intelligence (AI) has now reached industry and the consciousness of the population. The impressive successes and new AI methods are now so relevant that they should be taught even in a basic course. In about 30 new pages, I report mainly on *deep learning*, a consistent further development of neural networks, which finally enables image processing systems to recognize almost any object in pixel images. Among other benefits, this lead to the first computer program that could beat one of the world's best Go players.

In the new section on Deep Learning, we must not leave out a short report about the fascinating new subarea of *creativity*. For the first time neural networks can creatively generate texts, music pieces, and even paintings in the style of the old masters. These achievements are based on many years of research on neural networks and machine learning. Practical AI has developed into an engineering discipline in which programs are developed in large industrial teams by experts from various specializations.

Self-driving cars, service robots, and smart homes—which are all applications of AI—will greatly change our lives. However, in addition to great rays of hope, there will be a dark side. Though we live in a time of rapid technological progress, we have long since exceeded the limits of growth. We must therefore think about sustainability when implementing each new invention. In Chap. 1, I would like to give you some food for thought about this topic.

Other new additions to the book include a section on performance evaluation of clustering algorithms and two practical examples explaining Bayes' theorem and its relevance in everyday life. Finally, in a section on search algorithms, we analyze the cycle check, explain route planning for car navigation systems, and briefly introduce Monte Carlo Tree Search.

All known errors have been corrected and updates have been made in many places.

I would like to sincerely thank the readers who have given me feedback and all those who contributed to this new edition through proofreading and suggestions.

I would especially like to thank Adrian Batzill for the route planning measurements and graphs, as well as Nate Black, Nicole Dathe, Markus Schneider, Robin Lehmann, Ankita Agrawal, Wenzel Massag, Lars Berge, Jonas Lang, and Richard Cubek.

Ravensburg Wolfgang Ertel
March 2017

Preface to the First Edition

Artificial Intelligence (AI) has the definite goal of understanding intelligence and building intelligent systems. However, the methods and formalisms used on the way to this goal are not firmly set, which has resulted in AI consisting of a multitude of subdisciplines today. The difficulty in an introductory AI course lies in conveying as many branches as possible without losing too much depth and precision.

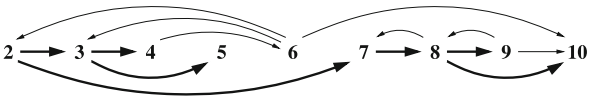
Russell and Norvig's book [RN10] is more or less the standard introduction into AI. However, since this book has 1,152 pages, and since it is too extensive and costly for most students, the requirements for writing this book were clear: it should be an accessible introduction to modern AI for self-study or as the foundation of a four-hour lecture, with at most 300 pages. The result is in front of you.

In the space of 300 pages, a field as extensive as AI cannot be fully covered. To avoid turning the book into a table of contents, I have attempted to go into some depth and to introduce concrete algorithms and applications in each of the following branches: agents, logic, search, reasoning with uncertainty, machine learning, and neural networks.

The fields of image processing, fuzzy logic, and natural language processing are not covered in detail. The field of image processing, which is important for all of computer science, is a stand-alone discipline with very good textbooks, such as [GW08]. Natural language processing has a similar status. In recognizing and generating text and spoken language, methods from logic, probabilistic reasoning, and neural networks are applied. In this sense this field is part of AI. On the other hand, computer linguistics is its own extensive branch of computer science and has much in common with formal languages. In this book we will point to such appropriate systems in several places, but not give a systematic introduction. For a first introduction in this field, we refer to Chaps. 22 and 23 in [RN10]. Fuzzy logic, or fuzzy set theory, has developed into a branch of control theory due to its primary application in automation technology and is covered in the corresponding books and lectures. Therefore we will forego an introduction here.

The dependencies between chapters of the book are coarsely sketched in the graph shown below. To keep it simple, Chap. 1, with the fundamental introduction for all further chapters, is left out. As an example, the thicker arrow from 2 to 3 means that propositional logic is a prerequisite for understanding predicate logic.

The thin arrow from 9 to 10 means that neural networks are helpful for understanding reinforcement learning, but not absolutely necessary. Thin backward arrows should make clear that later chapters can give more depth of understanding to topics which have already been learned.



This book is applicable to students of computer science and other technical natural sciences and, for the most part, requires high school level knowledge of mathematics. In several places, knowledge from linear algebra and multidimensional analysis is needed. For a deeper understanding of the contents, actively working on the exercises is indispensable. This means that the solutions should only be consulted after intensive work with each problem, and only to check one's solutions, true to Leonardo da Vinci's motto "Study without devotion damages the brain". Somewhat more difficult problems are marked with ❄, and especially difficult ones with ❄❄. Problems which require programming or special computer science knowledge are labeled with ➳.

On the book's web site at http://www.hs-weingarten.de/~ertel/aibook digital materials for the exercises such as training data for learning algorithms, a page with references to AI programs mentioned in the book, a list of links to the covered topics, a clickable list of the bibliography, an errata list, and presentation slides for lecturers can be found. I ask the reader to please send suggestions, criticisms, and tips about errors directly to ertel@hs-weingarten.de.

This book is an updated translation of my German book "Grundkurs Künstliche Intelligenz" published by Vieweg Verlag. My special thanks go to the translator Nathan Black who in an excellent trans-Atlantic cooperation between Germany and California via SVN, Skype and Email produced this text. I am grateful to Franz Kurfeß, who introduced me to Nathan; to MatthewWight for proofreading the translated book and to Simon Rees from Springer Verlag for his patience.

I would like to thank my wife Evelyn for her support and patience during this time consuming project. Special thanks go to Wolfgang Bibel and Chris Lobenschuss, who carefully corrected the German manuscript. Their suggestions and discussions lead to many improvements and additions. For reading the corrections and other valuable services, I would like to thank Richard Cubek, Celal Döven, Joachim Feßler, Nico Hochgeschwender, Paul Kirner, Wilfried Meister, Norbert Perk, Peter Radtke, Markus Schneider, Manfred Schramm, Uli Stärk, Michel Tokic, Arne Usadel and all interested students. My thanks also go out to Florian Mast for the priceless cartoons and very effective collaboration.

I hope that during your studies this book will help you share my fascination with Artificial Intelligence.

Ravensburg Wolfgang Ertel
February 2011

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