Recent Advances in Reinforcement Learning-Based Autonomous Driving Behavior Planning: A Survey

Jingda Wu, Chao Huang, Hailong Huang, Chen Lv, Yuntong Wang, and Fei-Yue Wang

Abstract—Autonomous driving (AD) holds the potential to revolutionize transportation efficiency, but its success hinges on robust behavior planning (BP) mechanisms. Reinforcement learning (RL) emerges as a pivotal tool in crafting these BP strategies. This paper offers a comprehensive review of RL-based BP strategies, spotlighting advancements from 2021 to 2023. We completely organize and distill the relevant literature, emphasizing paradigm shifts in RL-based BP. Introducing a novel categorization, we trace the trajectory of efforts aimed at surmounting practical challenges encountered by autonomous vehicles through innovative RL techniques. To guide readers, we furnish a quantitative analysis that maps the volume and diversity of recent RL configurations, elucidating prevailing trends. Additionally, we delve into the imminent challenges and potential directions for the future of RL-driven BP in AD. These directions encompass addressing safety vulnerabilities, fostering continual learning capabilities, enhancing data efficiency, championing collaborative vehicular cloud networks, integrating large language models, and enhancing ethical considerations.

Index Terms—Autonomous driving, reinforcement learning, behavior planning, decision, autonomous vehicle.

I. INTRODUCTION

AUTONOMOUS driving (AD) has the potential to enhance transportation efficiency and boost societal well-being [1]–[3]. Over the past few years, this subject has attracted significant scholarly attention [4]. Currently, two main architectural approaches dominate AD systems: the pipeline style and the end-to-end style [5]. In both architectures, the behavior planning (BP) module plays a crucial role in dictating autonomous vehicle (AV) actions and has become a central point of academic exploration [6]–[8]. The rise of data-driven approaches and the rapid evolution of machine intelligence have positioned reinforcement learning (RL) algorithms [9], renowned for their robust representational abilities [10] and optimization effectiveness [11], at the forefront of strategies for autonomous driving behavior planning (ADBP) [12].

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The acronyms used in this paper can be found in the appendix A1.
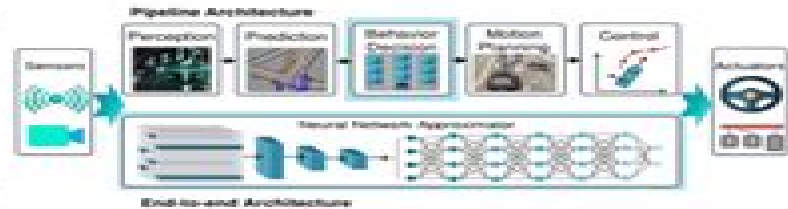
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Fig. 1. Schematic representation of two AD architectures. The top branch depicts the pipeline-style architecture, comprised of sequential functions with an explicit BP function named behavior decision (highlighted). The bottom branch illustrates the end-to-end neural network-based architecture that seamlessly integrates all functions, implicitly encompassing the BP function.

Initial studies in this domain focused on directly utilizing classical RL algorithms to craft a functional decision agent for real-time vehicle behavior generation using environmental perception data. This focus led to an extensive body of related literature [13]–[16]. For a thorough understanding of these early endeavors (up to 2021), we recommend several comprehensive reviews [17]–[24]. However, as the research has advanced, certain limitations of classical RL techniques, including safety, data efficiency, and generalization challenges, have surfaced. As a result, RL-based BP research has predominantly remained within academic confines, with limited appeal for commercial applications. In the recent three years, there has been an upswing in ADBP studies targeting these limitations through innovative RL theories. Yet, there is a dearth of reviews that holistically encapsulate these contemporary investigations.

This gap motivates us to provide a comprehensive overview of RL-based BP strategies from the last three years (2021–2023) and outline future directions. Our contributions include:

- A synthesis of the latest literature on RL-based BP strategies, spotlighting the innovative shifts in recent years.
- A novel categorization perspective that is uniquely anchored on addressing practical challenges faced by RL-based AVs using cutting-edge RL theories.
- A quantitative assessment for recent studies based on their diverse RL configurations.
- Insights of challenges and promising avenues in RL-based BP.

The subsequent sections are organized as follows: Section 2 introduces the fundamental concepts and prevailing classifications of ADBP strategies. Section 3 covers the basics of RL and highlights various new approaches used to address the deficiencies in the classical RL theory. Section 4 presents

Recent Advances In Reinforcement Learning

Sertan Girgin,Manuel Loth,Rémi Munos,Philippe Preux,Daniil Ryabko

Recent Advances In Reinforcement Learning:

Recent Advances in Reinforcement Learning Leslie Pack Kaelbling,1996-03-31 Recent Advances in Reinforcement Learning addresses current research in an exciting area that is gaining a great deal of popularity in the Artificial Intelligence and Neural Network communities Reinforcement learning has become a primary paradigm of machine learning It applies to problems in which an agent such as a robot a process controller or an information retrieval engine has to learn how to behave given only information about the success of its current actions This book is a collection of important papers that address topics including the theoretical foundations of dynamic programming approaches the role of prior knowledge and methods for improving performance of reinforcement learning techniques These papers build on previous work and will form an important resource for students and researchers in the area Recent Advances in Reinforcement Learning is an edited volume of peer reviewed original research comprising twelve invited contributions by leading researchers This research work has also been published as a special issue of Machine Learning Volume 22 Numbers 1 2 and 3 Recent Advances in Reinforcement Learning Sertan Girgin,Manuel Loth,Rémi Munos,Philippe Preux,Daniil Ryabko,2008-12 This book constitutes revised and selected papers of the 8th European Workshop on Reinforcement Learning EWRL 2008 which took place in Villeneuve d Ascq France during June 30 July 3 2008 The 21 papers presented were carefully reviewed and selected from 61 submissions They are dedicated to the field of and current researches in reinforcement learning *Recent Advances in Reinforcement Learning* Scott Sanner,Marcus Hutter,2012-05-19 This book constitutes revised and selected papers of the 9th European Workshop on Reinforcement Learning EWRL 2011 which took place in Athens Greece in September 2011 The papers presented were carefully reviewed and selected from 40 submissions The papers are organized in topical sections online reinforcement learning learning and exploring MDPs function approximation methods for reinforcement learning macro actions in reinforcement learning policy search and bounds multi task and transfer reinforcement learning multi agent reinforcement learning apprenticeship and inverse reinforcement learning and real world reinforcement learning Recent Advances in Reinforcement Learning Leslie Pack Kaelbling,2014-01-15 Recent Advances in Reinforcement Learning Leslie Pack Kaelbling,2007-08-28 Recent Advances in Reinforcement Learning addresses current research in an exciting area that is gaining a great deal of popularity in the Artificial Intelligence and Neural Network communities Reinforcement learning has become a primary paradigm of machine learning It applies to problems in which an agent such as a robot a process controller or an information retrieval engine has to learn how to behave given only information about the success of its current actions This book is a collection of important papers that address topics including the theoretical foundations of dynamic programming approaches the role of prior knowledge and methods for improving performance of reinforcement learning techniques These papers build on previous work and will form an important resource for students and researchers in the area Recent Advances in Reinforcement Learning is an edited volume of peer reviewed original research comprising

twelve invited contributions by leading researchers This research work has also been published as a special issue of Machine Learning Volume 22 Numbers 1 2 and 3   **Recent Advances in Reinforcement Learning** Sertan Girgin,Manuel Loth,Rémi Munos,Philippe Preux,Daniil Ryabko,2008-11-27 Inthesummerof2008 reinforcementlearningresearchersfromaroundtheworld gathered in the north of France for a week of talks and discussions on reinfor ment learning on how it could be made more e cient applied to a broader range of applications and utilized at more abstract and symbolic levels As a participant in this 8th European Workshop on Reinforcement Learning I was struck by both the quality and quantity of the presentations There were four full days of short talks over 50 in all far more than there have been at any p vious meeting on reinforcement learning in Europe or indeed anywhere else in the world There was an air of excitement as substantial progress was reported in many areas including Computer Go robotics and tted methods Overall the work reported seemed to me to be an excellent broad and representative sample of cutting edge reinforcement learning research Some of the best of it is collected and published in this volume The workshopandthe paperscollectedhere provideevidence thatthe eldof reinforcement learning remains vigorous and varied It is appropriate to re ect on some of the reasons for this One is that the eld remains focused on a pr lem sequential decision making without prejudice as to solution methods Another is the existence of a common terminology and body of theory   **Recent Advances in Reinforcement Learning** Leslie Pack Kaelbling,1996-03-31 Recent Advances in Reinforcement Learning addresses current research in an exciting area that is gaining a great deal of popularity in the Artificial Intelligence and Neural Network communities Reinforcement learning has become a primary paradigm of machine learning It applies to problems in which an agent such as a robot a process controller or an information retrieval engine has to learn how to behave given only information about the success of its current actions This book is a collection of important papers that address topics including the theoretical foundations of dynamic programming approaches the role of prior knowledge and methods for improving performance of reinforcement learning techniques These papers build on previous work and will form an important resource for students and researchers in the area Recent Advances in Reinforcement Learning is an edited volume of peer reviewed original research comprising twelve invited contributions by leading researchers This research work has also been published as a special issue of Machine Learning Volume 22 Numbers 1 2 and 3   Recent Advances in Artificial Intelligence Research and Development Jordi Vitrià,Petia Radeva,Isabel Aguiló,2004 Artificial Intelligence AI is a scientific field of longstanding tradition with origins in the early years of computer science Today AI has reached a level of maturity that allows us to build highly sophisticated systems which perform very different tasks Nevertheless its evolution has opened up a number of new problems ranging from specific algorithms to system integration which remain elusive and assure a long life for this research field Research progress in this area is today an international challenge that must be supported by world class meetings and organizations but in spite of this fact there is also an objective need for meetings and organizations that support and disseminate research

at other levels This book focuses on new and original research on Artificial Intelligence **Recent Advances in Sciences, Engineering, Information Technology & Management** Dinesh Goyal,Bhanu Pratap,Sandeep Gupta,Saurabh Raj,Rekha Rani Agrawal,Indra Kishor,2025-02-14 This conference covered various interdisciplinary areas such as applied science physics material science and engineering The audience got a chance to encircle the various interdisciplinary areas and people working on recent technologies in science engineering information technology and management It was based on the theme of converging interdisciplinary topics into a single platform which helped the participants to think beyond their area and increase their canvas of research Recent Advances in Materials and Manufacturing Technology Ramesh Kumar Nayak,Mohan Kumar Pradhan,Animesh Mandal,J. Paulo Davim,2023-07-04 This book presents the select proceedings of the 2nd International Conference on Advances in Materials and Manufacturing Technology ICAMMT 2022 The book covers the latest trends in existing and new materials manufacturing processes evaluation of materials properties for the application in automotive aerospace marine locomotive automotive and energy sectors The topics covered include advanced metal forming bending welding and casting techniques recycling and re manufacturing of materials and components materials processing characterization and applications multi physics coupling simulation and optimization alternate materials material substitution thermally enhanced processes and materials composites and polymer manufacturing powder metallurgy and ceramic forming numerical modeling and simulation advanced machining processes functionally graded materials non destructive examination optimization techniques engineering materials heat treatment material testing MEMS integration energy materials bio materials metamaterials metallography nanomaterial SMART materials and super alloys In addition it discusses industrial applications and covers theoretical and analytical methods numerical simulations and experimental techniques in the area of advanced materials and their applications It also covers the application of artificial intelligence in advanced materials and manufacturing technology The book will be a valuable reference for researchers and industry professionals alike **Recent Advances in Learning Automata** Alireza Rezvanian,Ali Mohammad Saghiri,Seyed Mehdi Vahidipour,Mehdi Esnaashari,Mohammad Reza Meybodi,2018-01-17 This book collects recent theoretical advances and concrete applications of learning automata LAs in various areas of computer science presenting a broad treatment of the computer science field in a survey style Learning automata LAs have proven to be effective decision making agents especially within unknown stochastic environments The book starts with a brief explanation of LAs and their baseline variations It subsequently introduces readers to a number of recently developed complex structures used to supplement LAs and describes their steady state behaviors These complex structures have been developed because by design LAs are simple units used to perform simple tasks their full potential can only be tapped when several interconnected LAs cooperate to produce a group synergy In turn the next part of the book highlights a range of LA based applications in diverse computer science domains from wireless sensor networks to peer to peer networks to complex social networks and finally to Petri nets The book accompanies the reader on a

comprehensive journey starting from basic concepts continuing to recent theoretical findings and ending in the applications of LAs in problems from numerous research domains As such the book offers a valuable resource for all computer engineers scientists and students especially those whose work involves the reinforcement learning and artificial intelligence domains

A Review of Recent Advancements in Deep Reinforcement Learning Artur Sahakjan,2018-08-02 Bachelor Thesis from the year 2018 in the subject Computer Science Commercial Information Technology grade 1 0 University of Duisburg Essen language English abstract Reinforcement learning is a learning problem in which an actor has to behave optimally in its environment Deep learning methods on the other hand are a subclass of representation learning which in turn focuses on extracting the necessary features for the task e g classification or detection As such they serve as powerful function approximators The combination of those two paradigm results in deep reinforcement learning This thesis gives an overview of the recent advancement in the field The results are divided into two broad research directions value based and policy based approaches This research shows several algorithms from those directions and how they perform Finally multiple open research questions are addressed and new research directions are proposed   *Recent Advances in Internet of Things and Machine Learning* Valentina E. Balas,Vijender Kumar Solanki,Raghvendra Kumar,2022-02-14 This book covers a domain that is significantly impacted by the growth of soft computing Internet of Things IoT related applications are gaining much attention with more and more devices which are getting connected and they become the potential components of some smart applications Thus a global enthusiasm has sparked over various domains such as health agriculture energy security and retail So in this book the main objective is to capture this multifaceted nature of IoT and machine learning in one single place According to the contribution of each chapter the book also provides a future direction for IoT and machine learning research The objectives of this book are to identify different issues suggest feasible solutions to those identified issues and enable researchers and practitioners from both academia and industry to interact with each other regarding emerging technologies related to IoT and machine learning In this book we look for novel chapters that recommend new methodologies recent advancement system architectures and other solutions to prevail over the limitations of IoT and machine learning   Recent Advances in Applied Sciences Ritesh Bhat,Nithesh Naik,Ketan Kotecha,Antony V. Samrot,Sachi Nandan Mohanty,Bhaskar Somani,2025-06-07 This book commences with an editorial overview providing a comprehensive introduction to the current landscape and future prospects in engineering and technology Volume 1 of the International Conference on Innovative Discoveries and Emerging Advancements in Applied Sciences iDEAAS 2024 proceedings is a groundbreaking compilation that encapsulates the forefront of engineering and technological innovations This meticulously curated book serves as a cornerstone for professionals academics and students who are navigating the ever evolving realms of engineering and technology This sets the tone for a deep dive into a series of specialized topics In the aerospace and marine technologies section the book presents pioneering research and studies It offers insights into the latest advancements in aerospace

engineering delving into the complexities and innovations in aircraft and spacecraft design Simultaneously it explores the strides made in marine technologies highlighting the synergies and technological crossovers between these two critical fields The infrastructure and environment section addresses one of the most pressing concerns of the 21st century sustainable development This section is particularly insightful for its focus on the environmental impact of infrastructure development and the challenges of maintaining ecological balance Mechatronics and automation is another highlight of this volume where the fusion of mechanical engineering electronics and computing leads to fascinating innovations in automation and system design This section underscores the importance of interdisciplinary approaches in solving complex engineering problems and enhancing operational efficiency in various industries In the realm of computing and information technology the book explores the transformative impact of digital technologies on engineering The book culminates with a comprehensive summary that not only synthesizes the key themes discussed but also looks ahead at the future of engineering and technology It offers a visionary perspective on the emerging trends and potential advancements that are poised to redefine the engineering landscape **Recent Advances in Big Data, Machine, and Deep Learning for Precision Agriculture** Muhammad Fazal Ijaz,Marcin Wozniak,2024-02-19 *Recent Advances of Neural Network Models and Applications* Simone Bassis,Anna Esposito,Francesco Carlo Morabito,2013-12-19 This volume collects a selection of contributions which has been presented at the 23rd Italian Workshop on Neural Networks the yearly meeting of the Italian Society for Neural Networks SIREN The conference was held in Vietri sul Mare Salerno Italy during May 23 24 2013 The annual meeting of SIREN is sponsored by International Neural Network Society INNS European Neural Network Society ENNS and IEEE Computational Intelligence Society CIS The book as well as the workshop is organized in two main components a special session and a group of regular sessions featuring different aspects and point of views of artificial neural networks artificial and natural intelligence as well as psychological and cognitive theories for modeling human behaviors and human machine interactions including Information Communication applications of compelling interest **Recent Advances in Robot Learning** Judy A. Franklin,Tom M. Mitchell,Sebastian Thrun,2012-12-06 Recent Advances in Robot Learning contains seven papers on robot learning written by leading researchers in the field As the selection of papers illustrates the field of robot learning is both active and diverse A variety of machine learning methods ranging from inductive logic programming to reinforcement learning is being applied to many subproblems in robot perception and control often with objectives as diverse as parameter calibration and concept formulation While no unified robot learning framework has yet emerged to cover the variety of problems and approaches described in these papers and other publications a clear set of shared issues underlies many robot learning problems Machine learning when applied to robotics is situated it is embedded into a real world system that tightly integrates perception decision making and execution Since robot learning involves decision making there is an inherent active learning issue Robotic domains are usually complex yet the expense of using actual robotic hardware often prohibits

the collection of large amounts of training data Most robotic systems are real time systems Decisions must be made within critical or practical time constraints These characteristics present challenges and constraints to the learning system Since these characteristics are shared by other important real world application domains robotics is a highly attractive area for research on machine learning On the other hand machine learning is also highly attractive to robotics There is a great variety of open problems in robotics that defy a static hand coded solution Recent Advances in Robot Learning is an edited volume of peer reviewed original research comprising seven invited contributions by leading researchers This research work has also been published as a special issue of Machine Learning Volume 23 Numbers 2 and 3   Recent Advances in Memetic Algorithms William E. Hart,Natalio Krasnogor,J.E. Smith,2006-06-22 Memetic algorithms are evolutionary algorithms that apply a local search process to refine solutions to hard problems Memetic algorithms are the subject of intense scientific research and have been successfully applied to a multitude of real world problems ranging from the construction of optimal university exam timetables to the prediction of protein structures and the optimal design of space craft trajectories This monograph presents a rich state of the art gallery of works on memetic algorithms Recent Advances in Memetic Algorithms is the first book that focuses on this technology as the central topical matter This book gives a coherent integrated view on both good practice examples and new trends including a concise and self contained introduction to memetic algorithms It is a necessary read for postgraduate students and researchers interested in recent advances in search and optimization technologies based on memetic algorithms but can also be used as complement to undergraduate textbooks on artificial intelligence   Recent Advances in Optimization and its Applications in Engineering Moritz Diehl,Francois Glineur,Elias Jarlebring,Wim Michiels,2010-09-21 Mathematical optimization encompasses both a rich and rapidly evolving body of fundamental theory and a variety of exciting applications in science and engineering The present book contains a careful selection of articles on recent advances in optimization theory numerical methods and their applications in engineering It features in particular new methods and applications in the fields of optimal control PDE constrained optimization nonlinear optimization and convex optimization The authors of this volume took part in the 14th Belgian French German Conference on Optimization BFG09 organized in Leuven Belgium on September 14 18 2009 The volume contains a selection of reviewed articles contributed by the conference speakers as well as three survey articles by plenary speakers and two papers authored by the winners of the best talk and best poster prizes awarded at BFG09 Researchers and graduate students in applied mathematics computer science and many branches of engineering will find in this book an interesting and useful collection of recent ideas on the methods and applications of optimization   *Recent Advances in Management and Engineering* Ilona Paweloszek,Dorota Jelonek,Munish Sabharwal,Narendra Kumar,Karlibaeva Raya,2024-09-05 It is with great pleasure that I present to you the proceedings of our Recent Advances in Management and Engineering held on November 24 27 2023 in Male Maldives This conference represents a milestone in our ongoing journey towards academic excellence where we aspire

to become a renowned platform for the exchange of ideas collaboration networking and learning These proceedings contain contributions that are very amazing in innovations in management It covers a wide range of issues ranging from the most recent trends in business to innovations in fundamentals of management A broad collection of scholars practitioners and thought leaders from four continents across the world worked together to produce these results which are a reflection of their combined efforts

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