

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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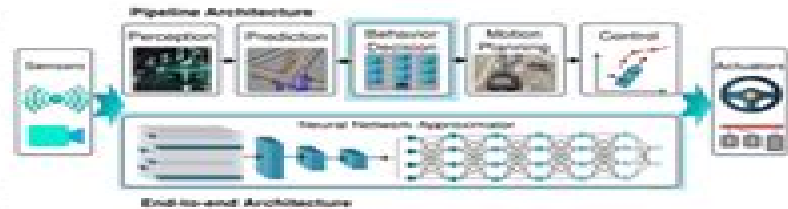


Fig. 1. Schematic representation of two AD architectures. The top branch depicts the pipeline-style architecture, comprised of sequential functions with an explicit BP function named behavior decision (highlighted). The bottom branch illustrates the end-to-end neural network-based architecture that seamlessly 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

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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 Sertan Girgin, Manuel Loth, Rémi Munos, Philippe Preux, Daniil Ryabko, 2008-11-27 In the summer of 2008 reinforcement learning researchers from around the world gathered in the north of France for a week of talks and discussions on reinforcement learning on how it could be made more efficient 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 previous 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 tried 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 workshop and the papers collected here provide evidence that the field of reinforcement learning remains vigorous and varied It is appropriate to reflect on some of the reasons for this One is that the field remains focused on a problem sequential decision making without prejudice as to solution methods Another is the existence of a common terminology and body of theory 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 nanomaterials 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 Deep Learning Applications Uche Onyekpe,Vasile Palade,M. Arif Wani,2025-11-19 This book presents a collection of rigorously revised papers selected from the 22nd IEEE International Conference on Machine Learning and Applications IEEE ICMLA 2023 It focuses on deep learning architectures and their applications in domains such as health care security and threat detection education fault diagnosis and robotic control in industrial environments Novel ways of using convolutional neural networks transformers autoencoders graph based neural networks and large language models for the above applications are covered in this book Readers will find insights to help them realize novel ways of using deep learning architectures and models in real world applications and contexts making this book an essential reference guide for academic researchers professionals software engineers in the industry and innovative product developers Key Features Presents state of the art research on deep learning Covers modern real world applications of deep learning Provides value to students academic researchers professionals software engineers in the industry and innovative product developers

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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 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 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 **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 Microelectronics Reliability Willem Dirk van Driel, Klaus Pressel, Mujdat Soyturk, 2024-07-12 This book describes the latest progress in reliability analysis of microelectronic products The content grows out of an EU project named Intelligent Reliability 4.0 iRel40 see www.irel40.eu Different industrial sectors and topics are covered such as electronics in automotive rail transport lighting and personal appliances Several case studies and examples are discussed which will enable readers to assess and mitigate similar failure cases More importantly this book tries to present methodologies and useful approaches in analyzing a failure and in relating a failure to the reliability of electronic devices

Recent Advances in Knowledge-based Paradigms and Applications Jeffrey W. Tweedale, Lakhmi C. Jain, 2013-10-30 This book presents carefully selected contributions devoted to the modern perspective of AI research and innovation This collection covers several areas of applications and motivates new research directions The theme across all chapters combines several domains of AI research Computational Intelligence and Machine Intelligence including an introduction to the recent research and models Each of the subsequent chapters reveals leading edge research and innovative solution that employ AI techniques with an applied perspective The problems include classification of spatial images early smoke detection in outdoor space from video images emergent segmentation from image analysis intensity modification in images multi agent modeling and analysis of stress They all are novel pieces of work and demonstrate how AI research contributes to solutions for difficult real world problems that benefit the research community industry and society

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 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 *Recent Advances in Computing Sciences* Sophiya Sheikh,Manmohan Sharma,Amar Singh,2023-12-21 The 1st International Conference on Recent Advances in Computing Sciences RACS 2022 organized by the School of Computer Application Lovely Professional University Jalandhar Punjab from 4th to 5th November 2022 The conference focuses on discussing issues exchanging ideas and the most recent innovations towards the advancement of research in the field of Computing Sciences and Technology All technical sessions were predominantly related to Data Science Artificial Intelligence Remote Sensing Image Processing Computer Vision Data Forensics Cyber Security Computational Sciences Simulation Modelling Business Analytics and Machine Learning The main objective of this conference is to provide a common platform for academia and industry to discuss various technological challenges and share cognitive thoughts It provided a thought provoking platform to discuss and disseminate novel solutions for real world problems in a dynamic and changing technological environment The main success of RACS 2022 is to give an opportunity for the participants to enhance their knowledge of recent computing technologies *Recent Advances in Artificial Intelligence in Cost Estimation in Project Management* Nevena Rankovic,Dragica Ranković,Mirjana Ivanovic,Ljubomir Lazić,2024-12-06 This book focuses on the practical application of AI tools and techniques in software project management offering detailed

theoretical explanations and practical examples of over 40 state of the art machine learning and deep learning algorithms applied across each project phase as well as in risk and resource management Helping the business world estimate projects more accurately while saving costs and resources is crucial in today s rapidly changing fast paced technological landscape Moreover it presents specific aspects of combined approaches through ensemble models incorporating Taguchi s optimization method to further improve estimation accuracy advancing this area of software project management A valuable resource for students and professionals to deepen their knowledge and skills it also serves as a great manual for companies adopting smarter strategies to manage and develop projects more efficiently and effectively

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