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Preface to the Special Issue on "Advances on Pursuit and Evasion Games and Applications"

Massimiliano Ferrara[1,2] · Gafurjan Ibragimov[3] · Shravan Luckraz[4] · Bruno Antonio Pansera[1]

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1 Introduction

Pursuit and evasion (PE) games constitute one of the most classical and enduring branches of differential game theory. Since the pioneering work of Rufus Isaacs [1], who laid the mathematical foundations of zero-sum differential games in the late 1950s and early 1960s, the problem of a pursuer seeking to intercept, or a family of pursuers seeking to capture, an evader that seeks to escape has attracted sustained attention across mathematics, control engineering, robotics, aeronautics, and operations research. The elegance of the formulation, with adversarial agents interacting continuously in time through a shared state space, which belies a remarkable depth that continues to generate new theoretical challenges and novel engineering applications more than half a century later.

The mathematical apparatus underpinning PE games draws on optimal control theory, Hamilton–Jacobi–Isaacs (HJI) equations, viability theory, geometric methods, and, increasingly, learning-based approaches rooted in reinforcement learning and neural networks. On the applications side, the reach of the framework now extends well beyond classical aerospace scenarios to encompass autonomous vehicle safety, multi-robot coordination, spacecraft maneuvering, mobile edge computing, and defense portfolio planning. This special issue collects a representative selection of recent advances across both the theoretical and applied

✉ Massimiliano Ferrara
massimiliano.ferrara@unirc.it

Gafurjan Ibragimov
ibragimov.math@gmail.com

Shravan Luckraz
Shravan.Luckraz@nottingham.edu.cn

Bruno Pansera
bruno.pansera@unirc.it

1 Department of Law, Economics and Human Sciences, Decisions_LAB, University "Mediterranea" of Reggio Calabria, Reggio Calabria, Italy

2 ICRIOS, Bocconi University, Milan, Italy

3 V.I. Romanovskii Institute of Mathematics, Uzbekistan Academy of Sciences, 100174 Tashkent, Uzbekistan

4 School of Economics, University of Nottingham Ningbo China, Zhejiang, China

frontiers of the field, with the goal of offering the research community a coherent snapshot of where the discipline stands today and where it is headed.

2 Theoretical Advances

Several contributions in this issue sharpen the analytical foundations of pursuit–evasion theory. A central challenge in classical PE games is the derivation of *complete* game solutions: closed-form characterizations of optimal strategies and value functions over the entire state space, including the singular surfaces that arise when two or more candidate optimal trajectories intersect.

Von Moll [10] provides exactly such a complete solution for the celebrated *Lady in the Lake* scenario, a problem in which a faster pursuer on a circular boundary must intercept an evader initially located on the interior of a disk. The full characterization of the value function and the associated barrier surface closes a long-standing open question in differential game theory, demonstrating that classical formulations still harbor deep analytical content.

Ruiz [2] examines a game between two kinematically identical Dubins cars in which the evader must escape a conic sensor field of the pursuer in minimum time. The Dubins car model, i.e., a constant-speed vehicle with bounded turning rate, is both a canonical benchmark for kinematic constraints in pursuit–evasion and a practically relevant model for fixed-wing unmanned aerial vehicles. The paper derives the optimal evading maneuver by exploiting the geometry of Dubins paths, providing explicit strategy constructions that complement existing results on minimum-time Dubins problems.

Luckraz and Pansera [11] address the existence of evasion strategies in a linear differential game under integral constraints on both players' controls. Integral constraints, which bound the cumulative energy expenditure rather than the instantaneous control magnitude, thus introducing non-trivial challenges for the application of standard sufficient conditions. The authors establish rigorous existence results that extend the range of physical scenarios amenable to analytical treatment.

Mozhegova [16] studies the *linear pursuit problem of capturing two coordinated evaders on time scales*, a framework that unifies continuous-time and discrete-time dynamics within a single formalism. By analyzing the problem through the lens of time-scale calculus, the paper identifies conditions under which a single pursuer can guarantee simultaneous or sequential capture of two cooperating evaders, contributing to the multi-target pursuit literature.

Makkapati and Comandur [5] investigate the role of *asymmetric information and deception* in differential games. Their study of desensitization strategies, in which a player reduces the sensitivity of the game outcome to uncertainty in the opponent's state or intentions, alongside deliberate deception mechanisms opens a connection between classical PE theory and information-theoretic game formulations. This direction is of growing relevance as autonomous systems increasingly operate in adversarial environments where sensor spoofing and information manipulation are realistic concerns.

3 Multi-Agent Systems and Coordination

The extension from single-pursuer, single-evader games to multi-agent settings introduces qualitatively new phenomena: cooperation among pursuers, coordination of multiple evaders, formation control, and the combinatorial complexity of role assignment. Several papers in this issue advance our understanding of these richer configurations.

Zhuang [6] studies coordination and control architectures in multi-agent systems specifically designed to improve performance in pursuit–evasion scenarios. The paper analyzes how communication topology and distributed decision rules affect the collective ability of a pursuer team to guarantee capture against an agile evader, connecting PE game theory with the broader literature on multi-agent consensus and formation control.

The contribution by Cong et al. [4] addresses autonomous spacecraft maneuvering under emergency conditions, modeling the avoidance problem through an observation-based method grounded in PE game principles. The aerospace setting demands particular attention to fuel constraints, orbital mechanics, and limited sensing, making it a valuable stress-test for game-theoretic maneuvering strategies.

4 Learning-Based and Computational Methods

A prominent theme running through this special issue is the integration of machine learning and deep reinforcement learning (DRL) techniques with classical pursuit–evasion game formulations. The combinatorial and continuous complexity of PE problems in high-dimensional state spaces has historically limited the applicability of exact analytical methods; learning-based approaches offer a promising pathway toward scalable approximations.

Shan [3] proposes a pursuit–evasion game-theoretic decision-making framework for collision avoidance in automated vehicles, combining game-theoretic reasoning with data-driven prediction to handle the multi-agent, non-cooperative character of urban traffic interactions. The paper bridges the PE game literature with autonomous driving, an application domain in which safety guarantees under adversarial agent behavior are of paramount importance.

Han and Guo [12] investigate the use of neural networks for optimizing PE game tactics, demonstrating that deep learning architectures can approximate near-optimal strategies in scenarios where the analytical solution is intractable. Their work contributes to the growing literature on physics-informed and game-informed neural networks for control.

Chen et al. [9] introduce a PE game model-based mobile edge computing system for efficient task scheduling in dynamic environments. The mapping of computational resource allocation to a pursuit–evasion framework is a creative application that illustrates the breadth of the PE paradigm beyond its traditional motion-planning context.

Innab and Alahmari [8] develop a hybrid bio-inspired optimized neural network for real-time evasion of multi-robot systems in dynamic environments. By combining evolutionary computation with deep learning, their approach achieves robust evasion performance under sensor noise and unpredictable pursuer behavior, with potential applications in swarm robotics and adversarial multi-robot scenarios.

Low et al. [13] study mobile robot control using a pursuit–evasion differential game strategy for double-integrator dynamics with deep reinforcement learning. The double-integrator model, which captures both position and velocity states, is a natural stepping stone between kinematic and fully dynamic vehicle models. The paper demonstrates that DRL-based controllers trained within a PE game framework generalize effectively across a range of initial conditions and environmental perturbations.

Zhang et al. [14] address the problem of UAV multi-target tracking through a PE game model combined with DRL, showing how a single UAV can maintain persistent surveillance of several evading targets by learning adaptive pursuit strategies. This contribution connects to the wider literature on autonomous aerial surveillance and persistent monitoring.

Jia et al. [15] present a novel bio-inspired optimized algorithm with deep learning for task assessment within a PE framework. Their approach leverages the structural analogy between optimization in pursuit–evasion scenarios and biological foraging strategies to derive computationally efficient solutions for task allocation under adversarial conditions.

5 Applications Beyond Classical Motion Planning

One of the most striking features of the current literature is the breadth of application domains to which pursuit–evasion reasoning has been extended. Two papers in this issue are emblematic of this trend.

Dağıstanlı [7] applies dynamic game and optimization principles to long-term defense industry project portfolio management, developing a mixed and holistic project prioritization approach. While formally distinct from kinematic PE games, the paper exploits the adversarial decision-making logic underlying game-theoretic formulations to manage competing priorities and resource constraints in complex institutional settings, a compelling demonstration that PE-inspired reasoning extends naturally to strategic management problems.

6 Concluding Remarks

The articles assembled in this special issue reflect the vitality and diversity of contemporary research in pursuit–evasion game theory. From classical analytical completions of foundational problems to cutting-edge integrations with deep reinforcement learning, from aerospace and robotics to mobile computing and portfolio management, the contributions collectively illustrate both the mathematical depth and the applied breadth of the field.

Several directions appear particularly promising for future research. The interplay between information asymmetry, deception, and optimal strategy, touched upon in this issue but still far from fully understood, represents a frontier where classical differential game theory can engage productively with information theory and mechanism design. The scalability challenge in multi-agent PE problems, where the curse of dimensionality limits exact analytical solutions, continues to motivate hybrid approaches that combine model-based game-theoretic structure with data-driven approximation. The extension of PE frameworks to stochastic dynamics, partial observations, and time-varying environments will likewise demand new theoretical tools, likely drawing on advances in mean-field game theory, robust control, and online learning.

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