Autonomous Agent for Beyond Visual Range Air Combat: A Deep Reinforcement Learning Approach

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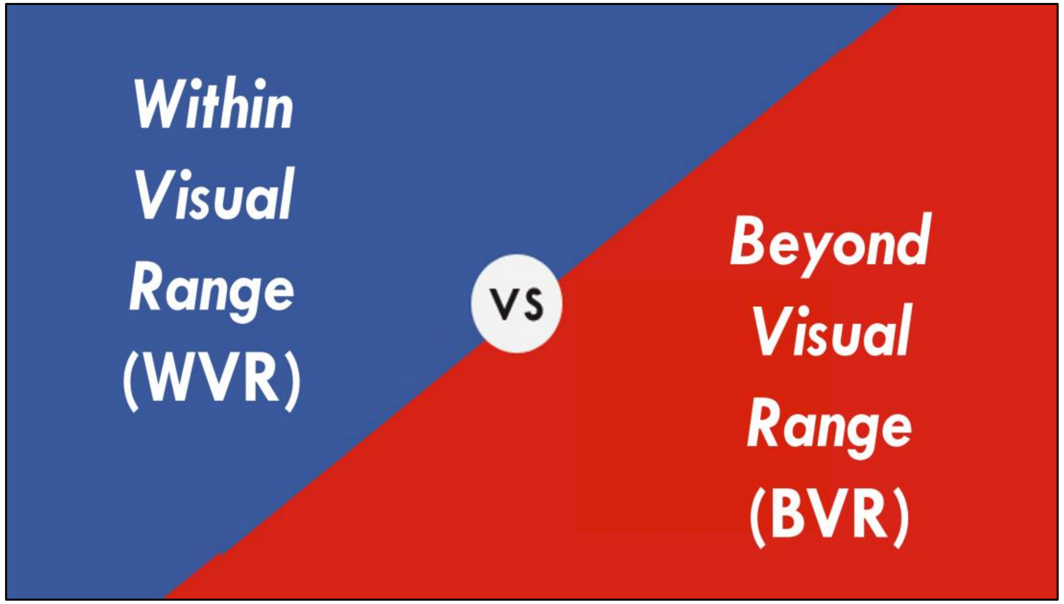
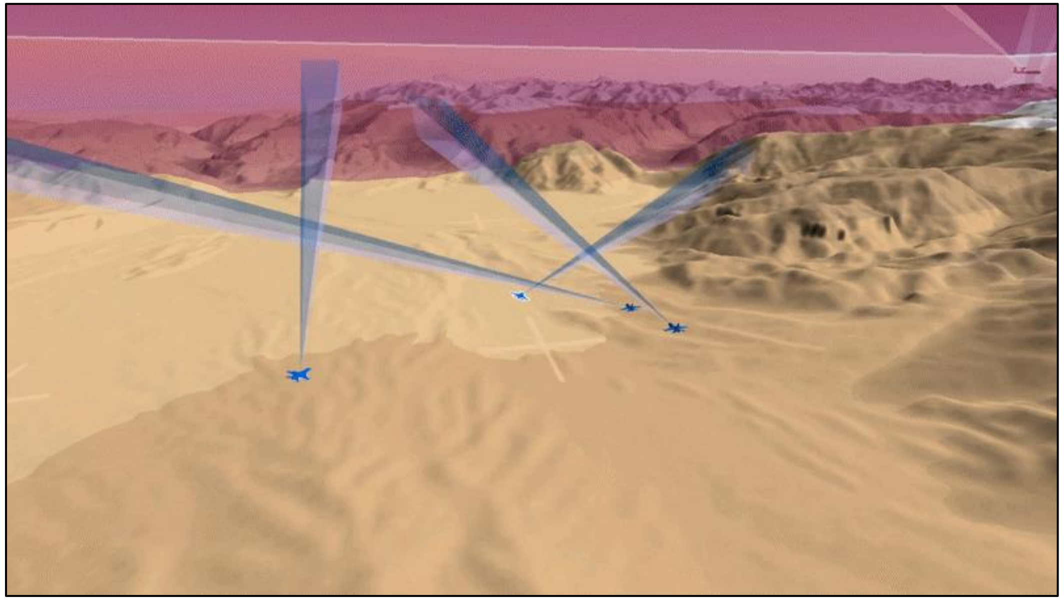
Introduction

- Within Visual Range (WVR) vs Beyond Visual Range (BVR)
- BVR air combat: Pilots engage without direct visual contact (~ 40 nautical miles)
- Technological innovation in modern warfare: Emergence of advanced sensors and weapons
- Artificial Intelligence era: The role of Unmanned Combat Aerial Vehicles (UCAVs)





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Contribution

- Proposing a Deep Reinforcement Learning (DRL) AI fighter for BVR air combat
- Operational metric-based learning: Representing high-performance fighter aircraft capable of enhancing capabilities over time
- Development of innovative air combat tactics through self-play experiments
- Facilitate interaction between actual pilots and trained AI agents within a common virtual simulation environment

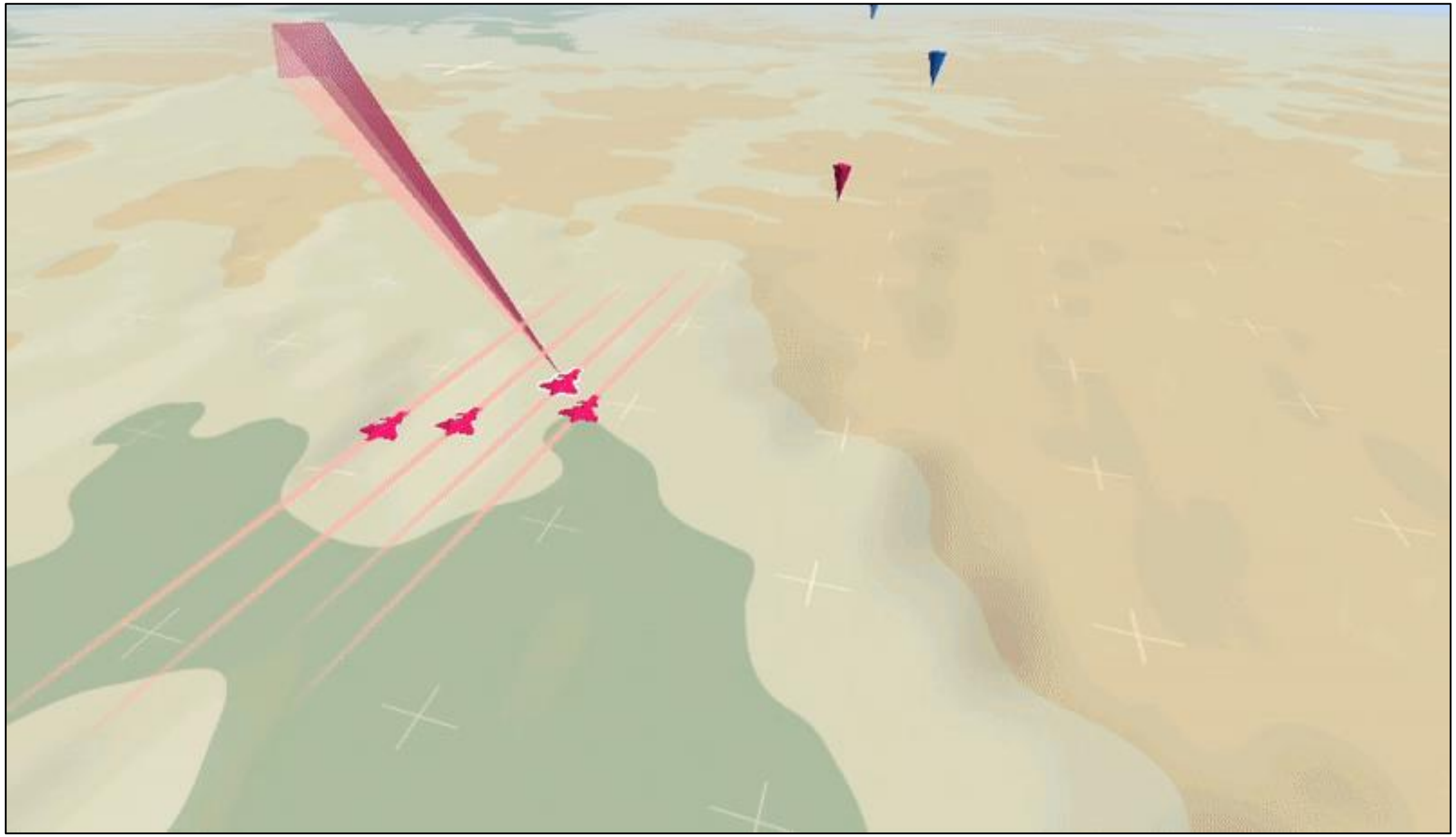
"This is the first work to propose a self-learning autonomous agent capable of mastering BVR air combat procedures and interacting with real fighter pilots in the same simulation environment"

Related Work

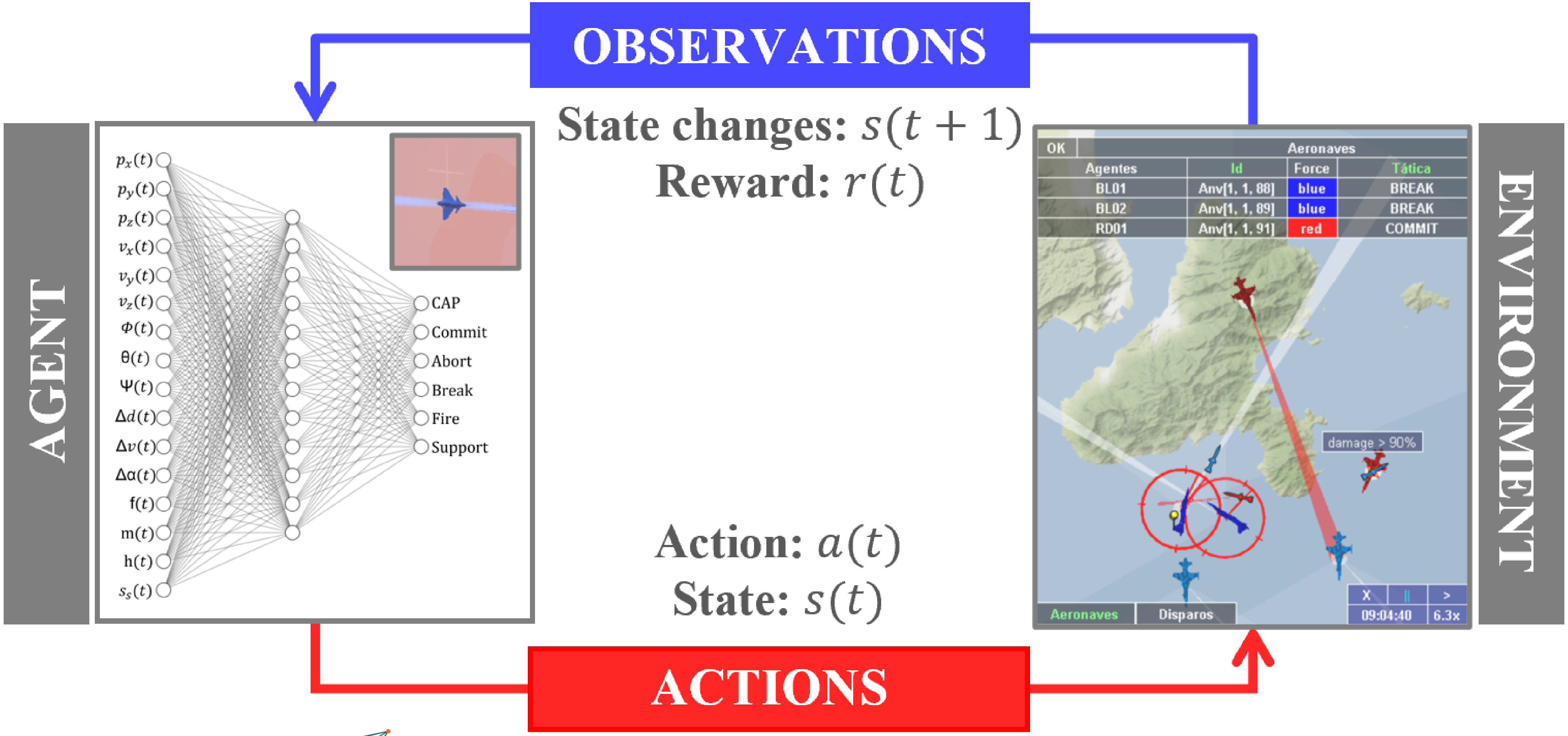
- Generation of air combat tactics (Piao et al., 2020)
- Strategic maneuver planning in air combat (Hu et al., 2021; Fan et al., 2022; Zhang et al., 2022)
- Innovations in multi-UAV cooperative decision-making methods (Liu et al., 2022; Hu et al., 2022)
- We still need robust algorithms and practical use of these methods
  - Application of DRL techniques to BVR air combat in a high-fidelity simulation environment
  - New research area: high-performance DRL agents capable of interacting with real fighter pilots

Aerospace Simulation Environment

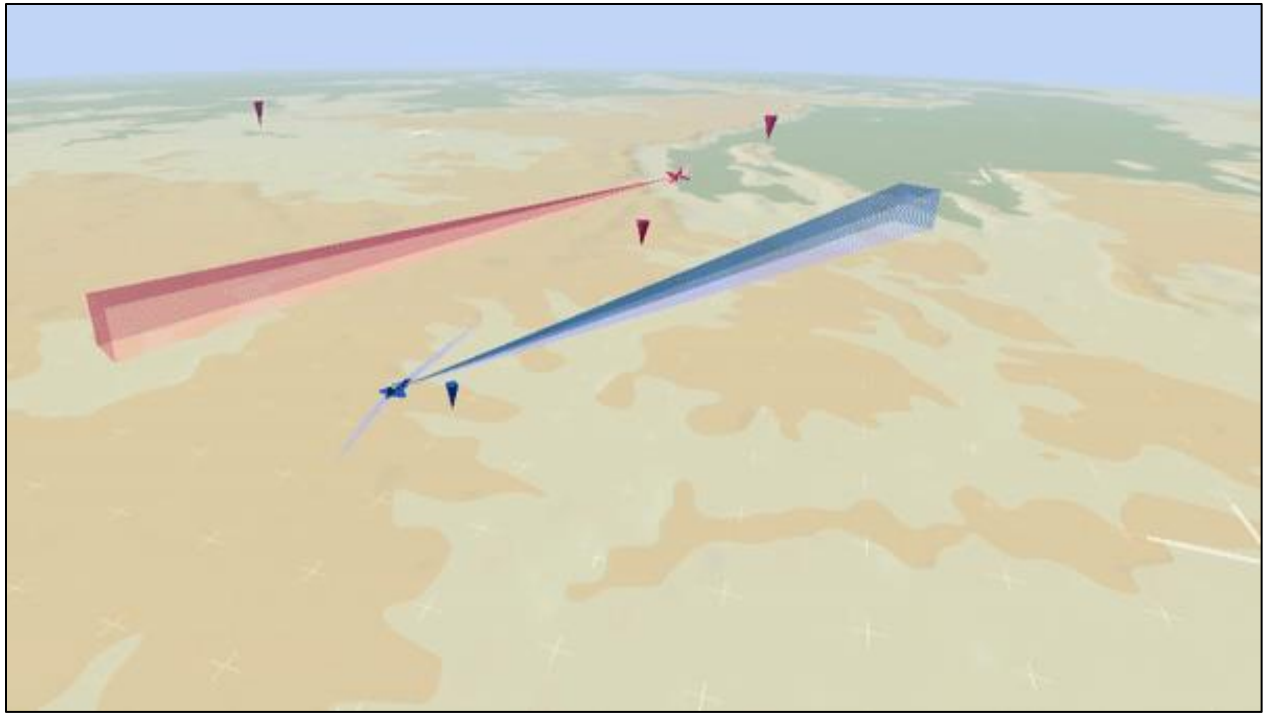
- Aerospace Simulation Environment – *Ambiente de Simulação Aeroespacial in Portuguese* (Dantas et al. 2022)
- Custom-made in C++ for advanced programming flexibility
- High-fidelity representation for accurate scenario reproduction
- Supported by the Brazilian Air Force
- Dedicated to modeling and simulation of military operational scenarios



Proposed Model



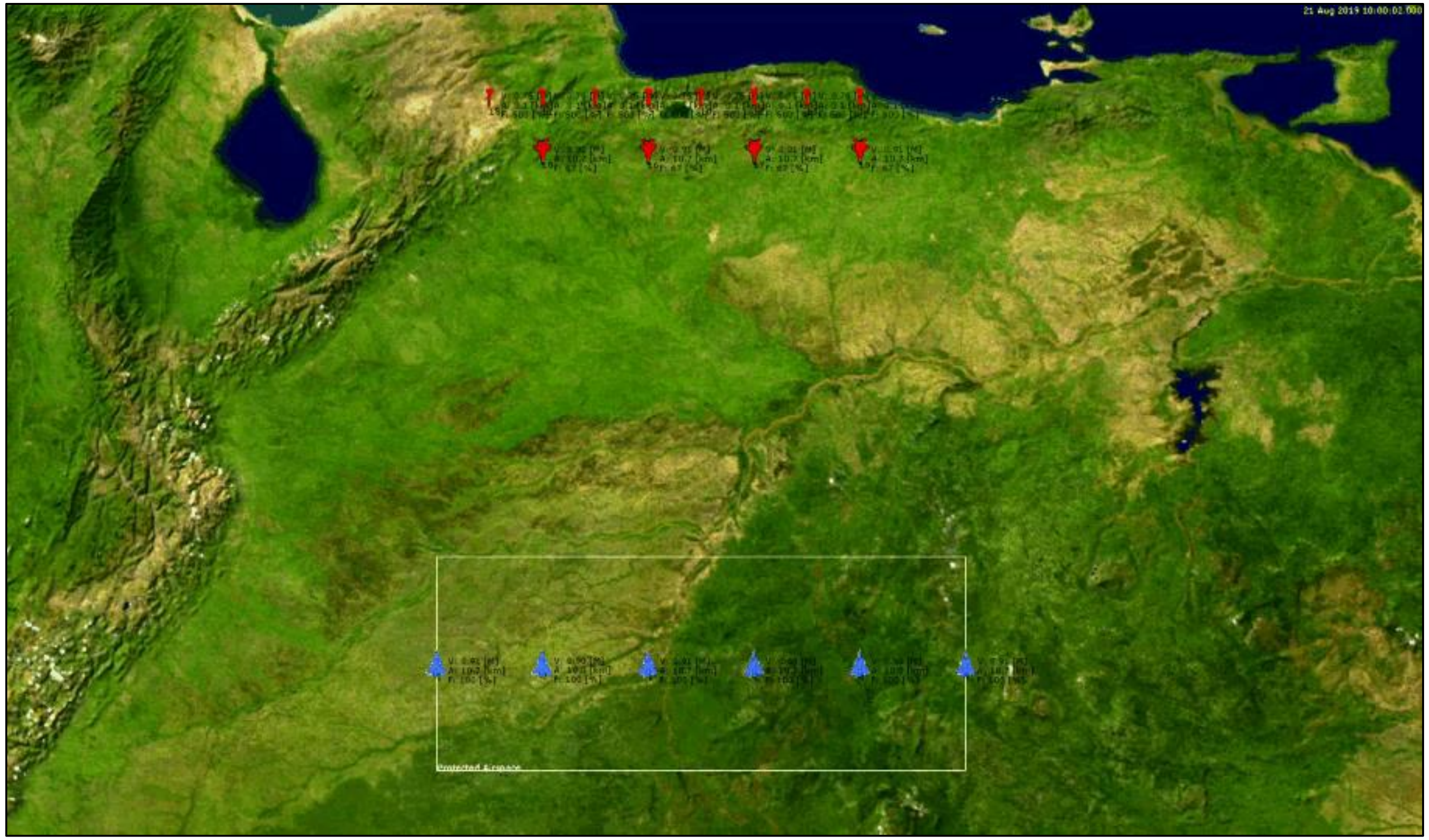
State $s(t)$



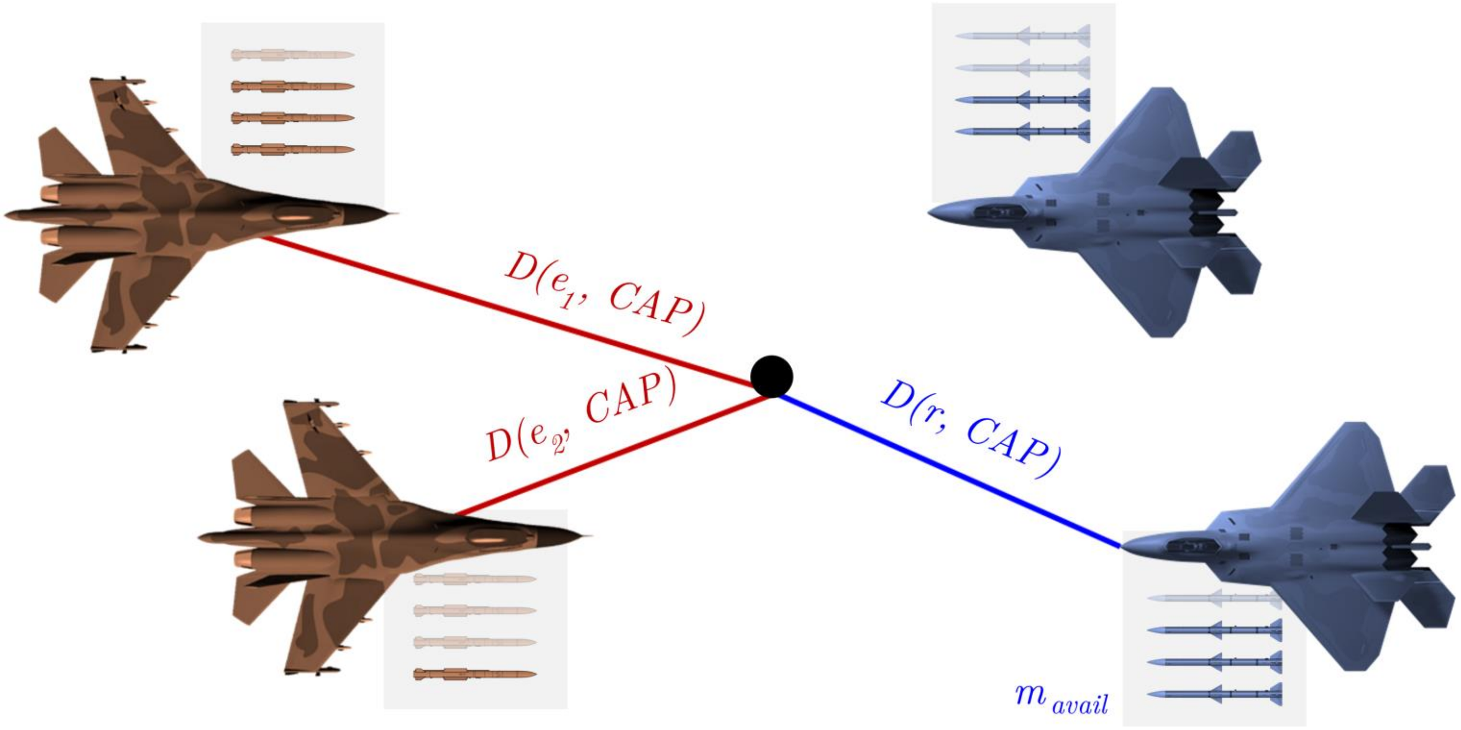
- Independent motion variable
  - Position $[px\ (t), py\ (t), pz\ (t)]$
  - Velocity $[vx\ (t), vy\ (t), vz\ (t)]$
  - Orientation [roll $\phi\ (t)$, pitch $\theta\ (t)$, yaw $\psi\ (t)$]
- Comparative factors between the agent and the nearest detected target
  - Relative distance $\Delta d\ (t)$
  - Relative speed $\Delta v\ (t)$
  - Relative angle $\Delta \alpha\ (t)$
- Agent's conditions
  - Remaining fuel $f\ (t)$
  - Remaining missiles $m(t)$
  - Health condition $h(t)$
  - Sensors' status $ss\ (t)$

Actions $a(t)$

- **CAP** – Keeping an orbit to monitor a specific area for enemy aircraft
- **COMMIT** – Switching to an offensive posture to threaten a key target
- **ABORT** – Shifting from offense to defense due to threats, loss of awareness, or task completion
- **BREAK** – Employing a final defense when threats exceed safety parameters
- **FIRE** – Meeting conditions to launch weapons against the enemy
- **SUPPORT** – Using radar to support the missile to the target, improving the success chances



Rewards $r(t)$



Defensive Counter Air (DCA) Index

$$I_{DCA} = w_1 \cdot \frac{m_{avail}}{m_{total}} + w_2 \cdot \frac{1}{1+\exp(-d_r)} + w_3 \cdot \frac{1}{N} \sum_{n=1}^{N} \frac{1}{1+\exp(-d_{e_n})}$$

Source: Dantas et al. (2021)

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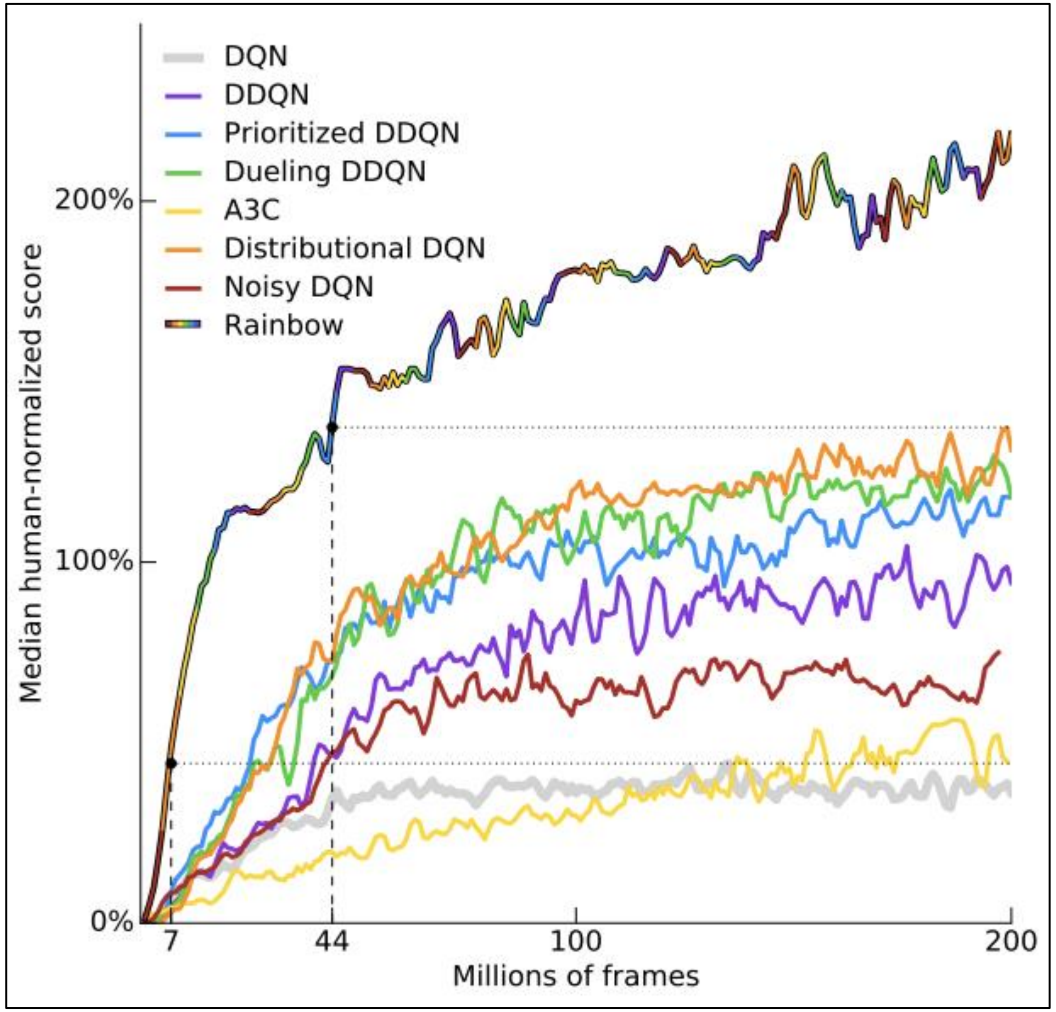
Cutting-Edge Algorithm

- **Rainbow Algorithm**
  - Provide a state-of-the-art performance (Hessel et al., 2017)
  - Combines several improvements to the Deep Q-Network algorithm (Mnih et al., 2015) to achieve better results
- **Subject Matter Expert Knowledge**
  - Enhancing Exploration and Exploitation
  - Shape reward functions for each application



Ongoing Research

- Conclude the testing phase of self-play experiments, utilizing AsaGym, an open-source Python library specifically designed for reinforcement learning in air combat scenarios
- More robust training and evaluation for the DRL agent
- Achieve the full integration of human pilots and AI fighters within a unified training environment

Conclusion

- Enhance the quality of air combat training through the development of UCAVs
- Advancing AI fighters to support pilots (Wingmen) or potentially even replace them
- Establish a Simulation-as-a-Service (SimaaS) platform to meet diverse aerospace and defense simulation demands
- **Future Work**
  - Execution of Turing Tests in collaboration with Brazilian fighter pilots, with the objective of assessing the competencies of the AI fighter
  - Incorporate the feedback gathered from the human pilots to iteratively enhance the AI fighter's operational performance and adaptability in real-world scenarios

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Biography

I am a Research Engineer in the Decision Support Systems Subdivision at the Institute for Advanced Studies (IEAv), a research organization of the Brazilian Air Force (FAB). My research focuses on defense applications, especially creating decision support systems to support FAB's mission. My long-term objective is to develop new national technologies on the edge of knowledge with a high added value to guarantee our technological sovereignty and to develop the Brazilian defense ecosystem. My work has been deployed in multiple defense applications, including air combat simulation, missile modeling, and autonomous agents in operational scenarios.

I received my B.Sc. degree in Mechanical-Aeronautical Engineering from the Aeronautics Institute of Technology (ITA), Brazil, in 2015. During this time, I participated in a year-long undergraduate exchange program at Stony Brook University, USA. I also received my M.Sc. degree from the Graduate Program in Electronic and Computer Engineering at ITA in 2019. Currently, I am pursuing my Ph.D. degree in the same program at ITA and, recently, I was working as a visiting researcher in the AirLab at Carnegie Mellon University. My research interests include Artificial Intelligence, Machine Learning, Robotics, and Simulation.

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