EVOLVING INTRINSIC MOTIVATIONS FOR ALTRUISTIC BEHAVIOR

EVOLVING INTRINSIC MOTIVATIONS FOR ALTRUISTIC BEHAVIOR

JANE X. | EDWARD H. | CHRISANTHA F. | WOJCHIECH M . | EDGAR A. | JOEL Z.

EVOLVING INTRINSIC MOTIVATIONS FOR ALTRUISTIC BEHAVIOR

JANE X. | EDWARD H. | CHRISANTHA F. | WOJCHIECH M . | EDGAR A. | JOEL Z.

DEEPMIND

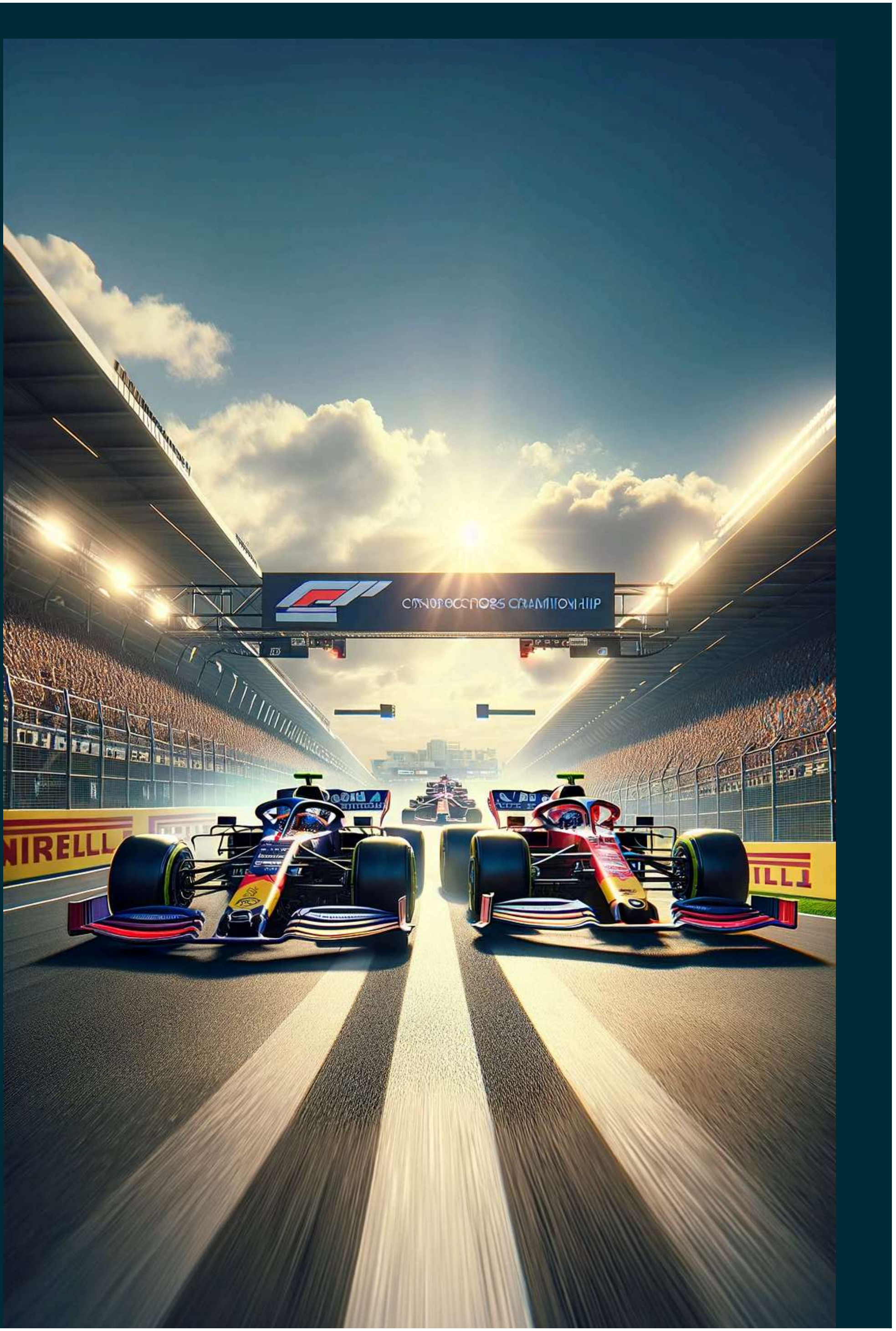
EVOLVING INTRINSIC MOTIVATIONS FOR ALTRUISTIC BEHAVIOR

JANE X. | EDWARD H. | CHRISANTHA F. | WOJCHIECH M . | EDGAR A. | JOEL Z.

DEEPMIND

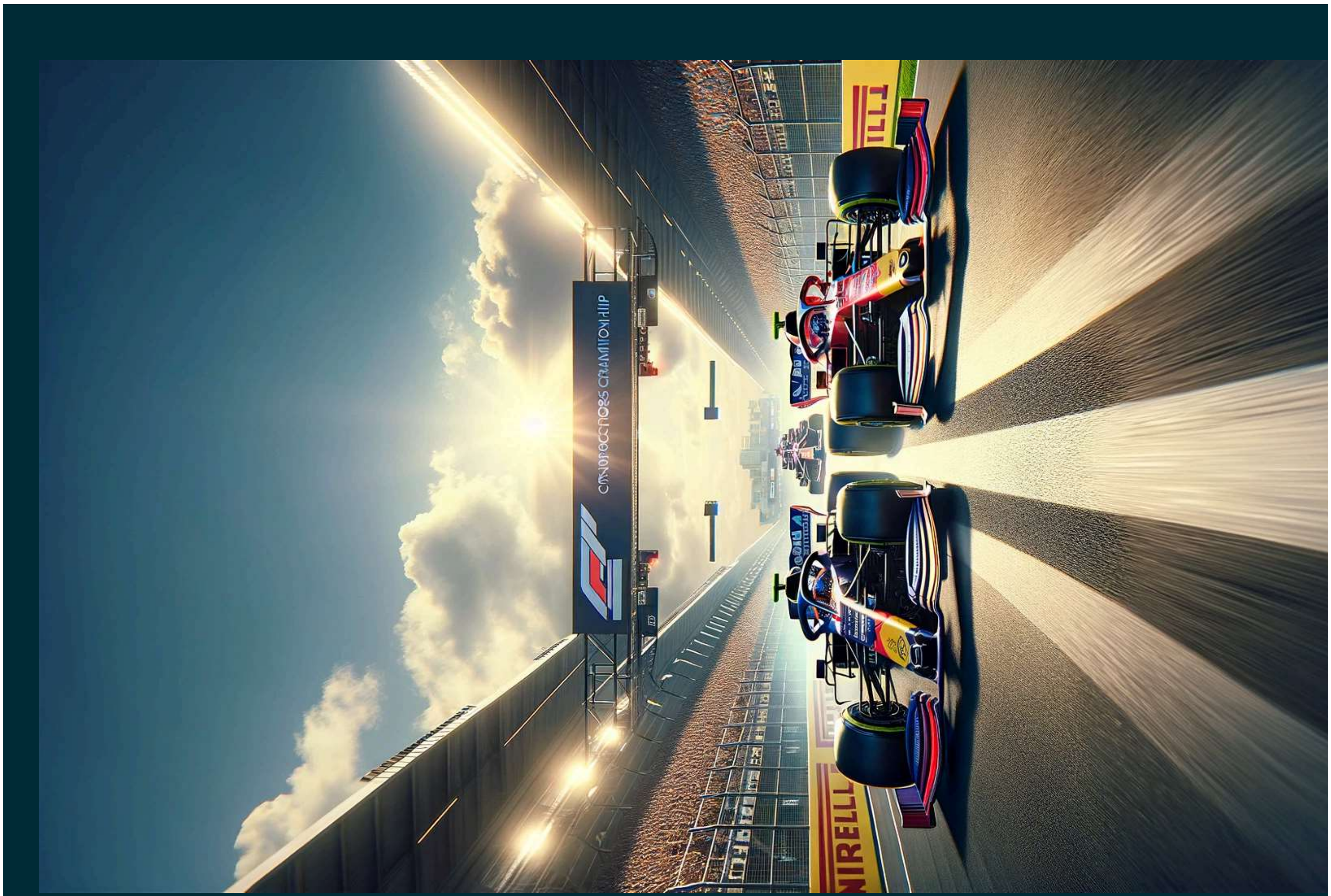
Self-Organising Agent Systems - Master in Artificial Intelligence - Mario R. O.

PAPER INTRODUCTION


NIRELLI
ILLI

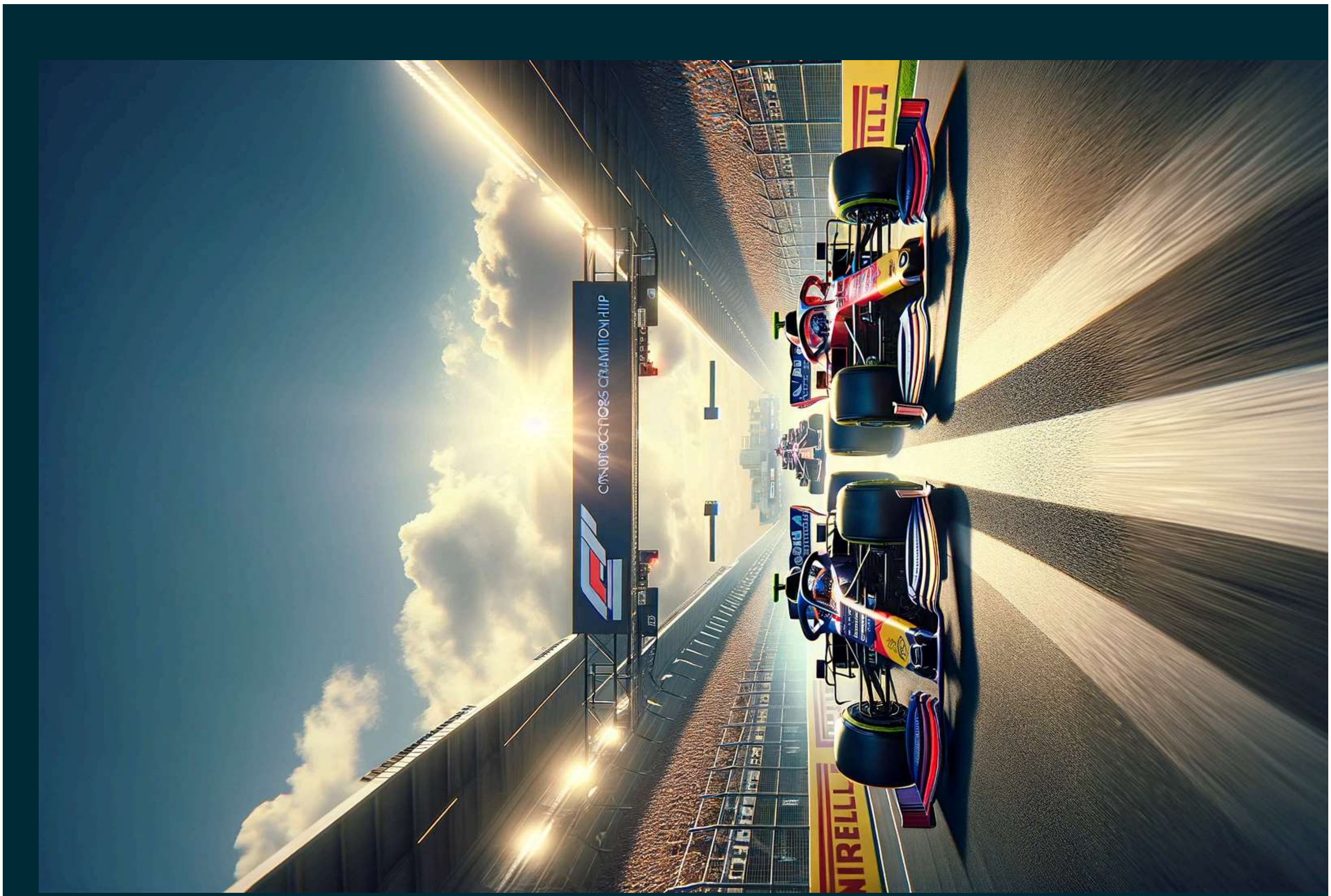
PAPER INTRODUCTION

- **Importance of Cooperation**: Working together towards a common goal, which is essential for achieving complex tasks and surviving in social and environmental challenges.



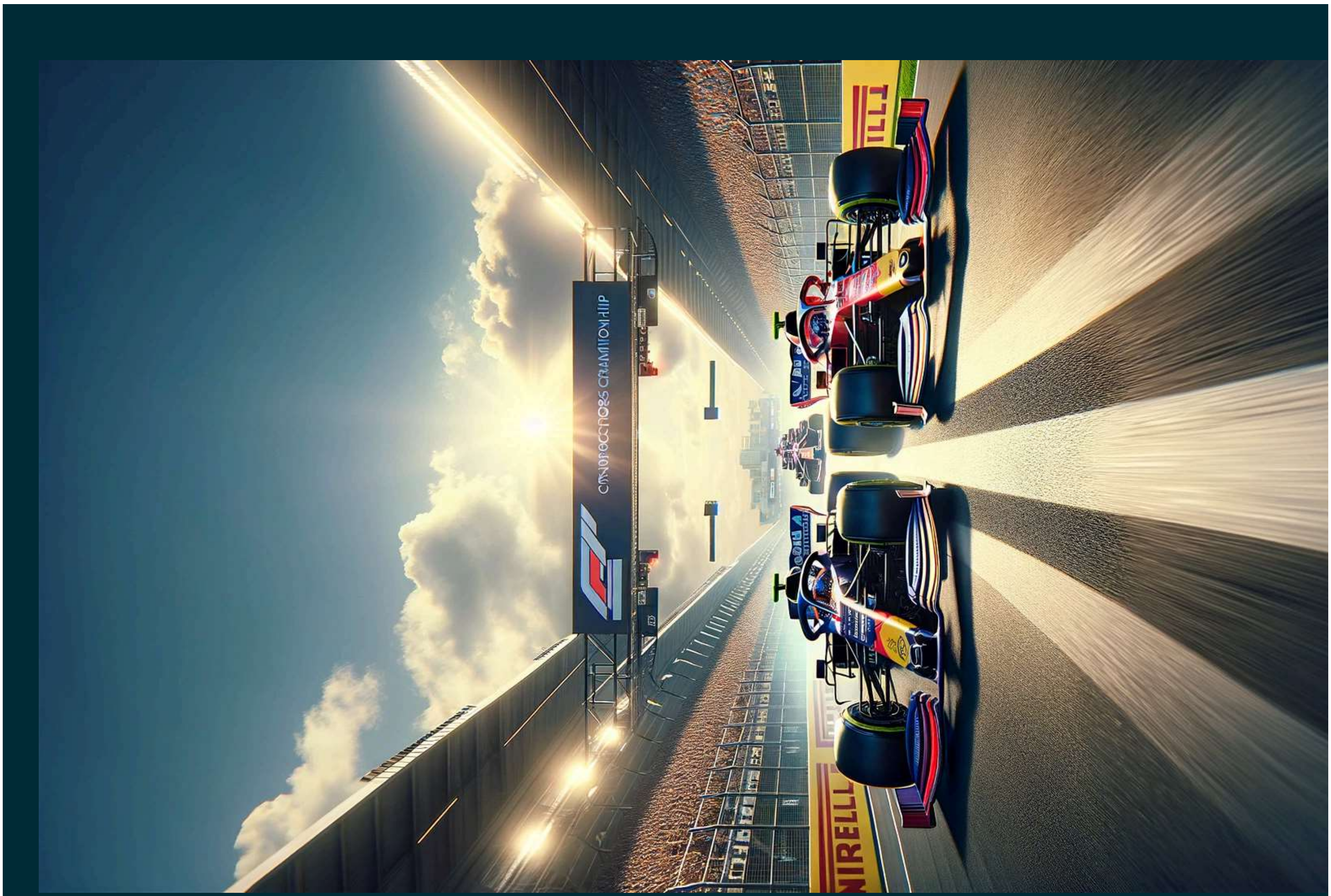
PAPER INTRODUCTION

- **Importance of Cooperation**: Working together towards a common goal, which is essential for achieving complex tasks and surviving in social and environmental challenges.
- **Intertemporal Social Dilemmas**: Situations where individuals must choose between immediate personal benefits and long-term collective well-being, highlighting the conflict between selfish actions and altruistic outcomes over time.


PIRELLI

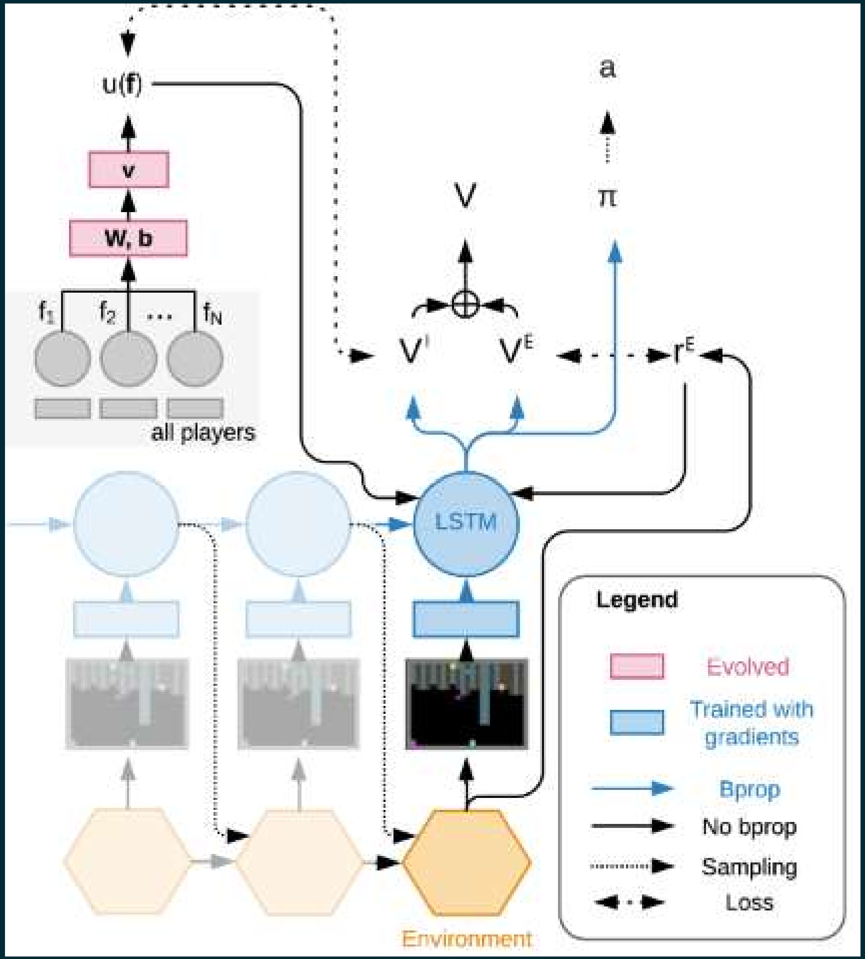
PAPER INTRODUCTION

- **Importance of Cooperation**: Working together towards a common goal, which is essential for achieving complex tasks and surviving in social and environmental challenges.
- **Intertemporal Social Dilemmas**: Situations where individuals must choose between immediate personal benefits and long-term collective well-being, highlighting the conflict between selfish actions and altruistic outcomes over time.
- **Evolution and Reinforcement Learning**: A process combining natural selection principles and learning strategies to adaptively improve behaviors or strategies based on feedback from the environment, aimed at achieving better outcomes over generations.

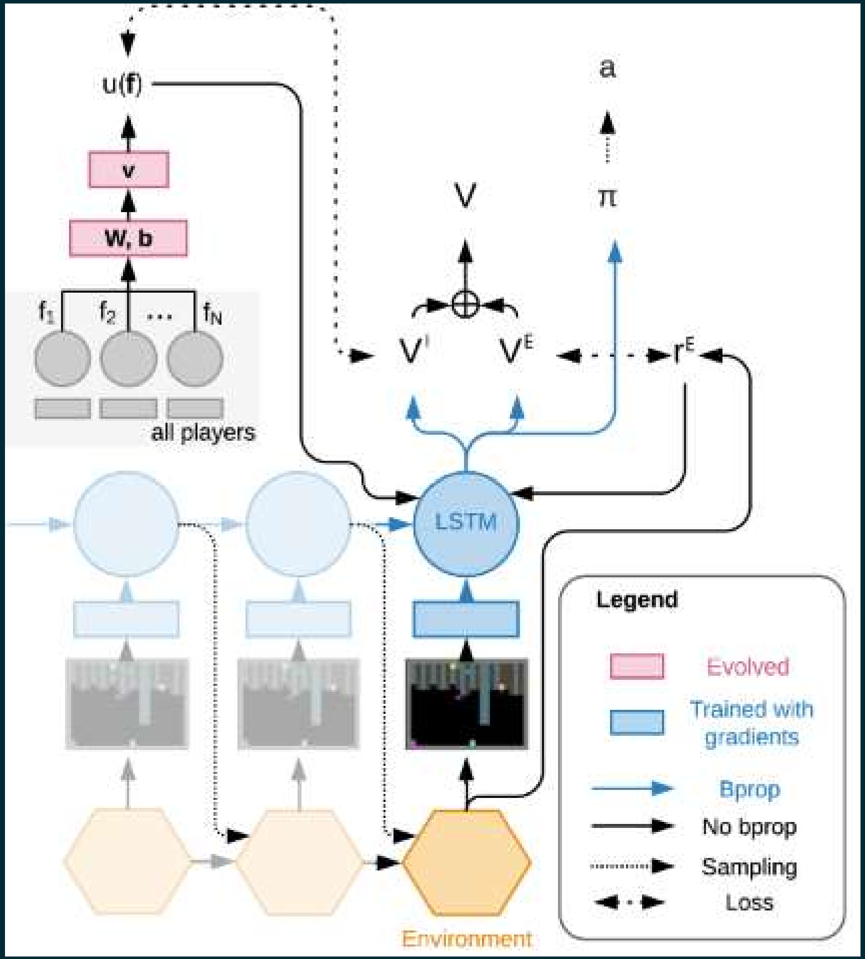


REWARD AND ADAPTATION METHODS

- Rewards
  - **Extrinsic Reward** : $r_i^E(s_i, a_i)$ feedback given by the environment for actions taken, reflecting immediate, tangible benefits.
  - **Intrinsic Reward**: $u(f)$ Additional rewards based on social features or the collective welfare, to promote cooperative behaviors.
  - **Total Reward**: The combination of extrinsic and intrinsic rewards, guiding overall agent behavior. $r_i(s_i, a_i) = r_i^E(s_i, a_i) + u_i(f_i)$

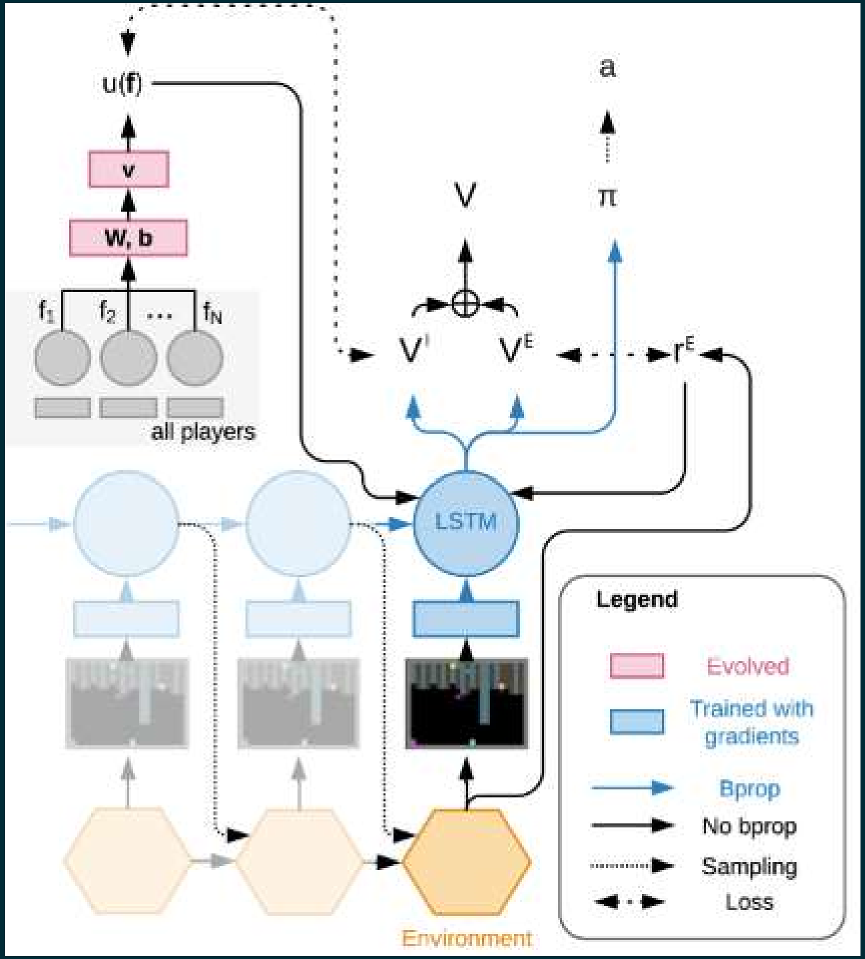


REWARD AND ADAPTATION METHODS

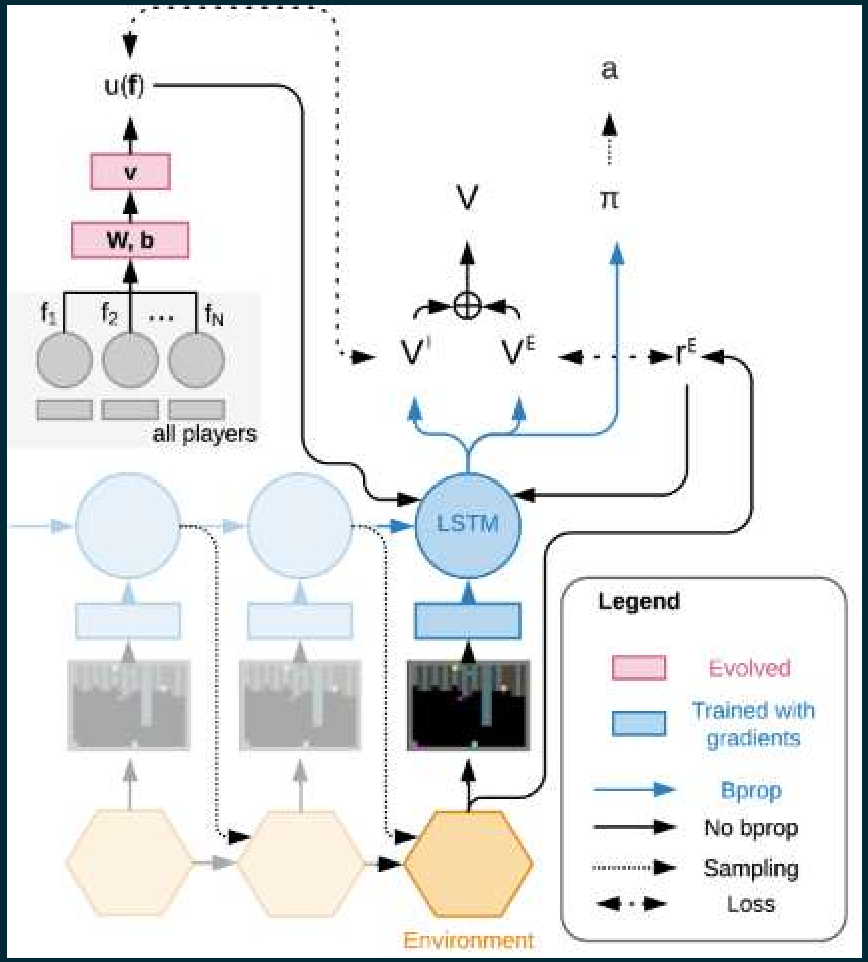


- Rewards
  - **Extrinsic Reward** : $r_i^E(s_i, a_i)$ feedback given by the environment for actions taken, reflecting immediate, tangible benefits.
  - **Intrinsic Reward**: $u(f)$ Additional rewards based on social features or the collective welfare, to promote cooperative behaviors.
  - **Total Reward**: The combination of extrinsic and intrinsic rewards, guiding overall agent behavior. $r_i(s_i, a_i) = r_i^E(s_i, a_i) + u_i(f_i)$

REWARD AND ADAPTATION METHODS



- Auxiliar concepts
  - **Feature vector** f: A set of characteristics observed or experienced derived from all players, used to compute the intrinsic reward via a neural network.
  - **Prospective Method**: Intrinsic rewards are calculated based on expectations of future rewards, aiming to influence immediate decisions for long-term benefits.
  - **Retrospective Method**: Intrinsic rewards are based on past actions' outcomes, focusing on historically received rewards, to encourage behaviors beneficial in similar future contexts.
  - **Evolutionary Approach**: Over time, the weightings within the intrinsic reward function evolve, optimizing the balance between extrinsic and intrinsic rewards to foster cooperative strategies.



REWARD AND ADAPTATION METHODS

- Auxiliar concepts
  - **Feature vector** f: A set of characteristics observed or experienced derived from all players, used to compute the intrinsic reward via a neural network.
  - **Prospective Method**: Intrinsic rewards are calculated based on expectations of future rewards, aiming to influence immediate decisions for long-term benefits.
  - **Retrospective Method**: Intrinsic rewards are based on past actions' outcomes, focusing on historically received rewards, to encourage behaviors beneficial in similar future contexts.
  - **Evolutionary Approach**: Over time, the weightings within the intrinsic reward function evolve, optimizing the balance between extrinsic and intrinsic rewards to foster cooperative strategies.

ARCHITECTURE: BUILDING THE AGENTS

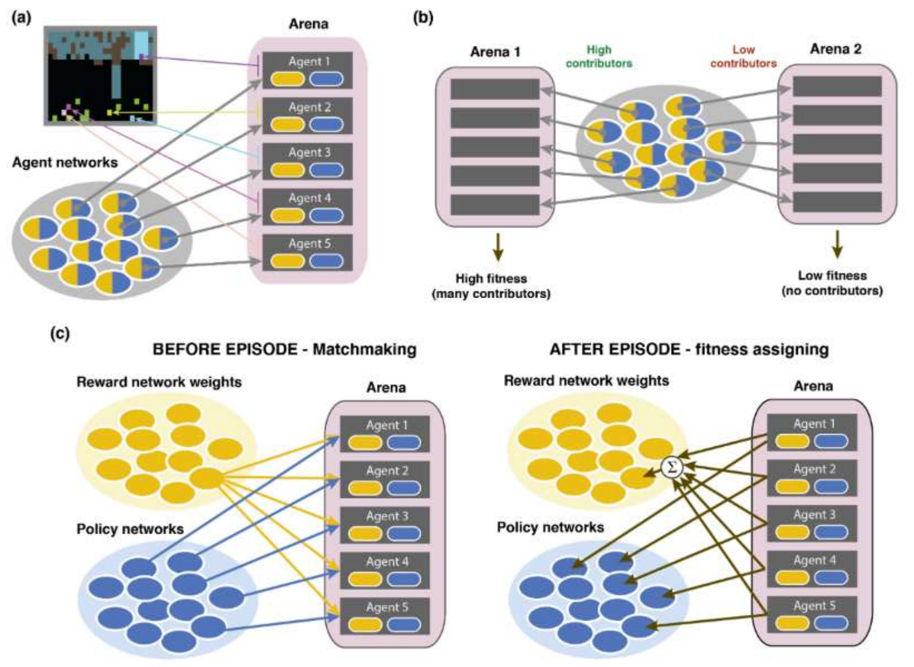
The agents are built using a deep reinforcement learning framework, each agent has:

- **Policy Network**: A neural network module which decides what actions to take based on what the agent sees in its environment.
- **Reward Network**: this network modifies the rewards the agent receives for certain actions, based on social factors.

EVOLUTIONARY DYNAMICS

- **Random vs Assortative Matchmaking**: Agents can be matched in two different ways: uniformly at random or based on their level of cooperativeness.

- **Shared vs. Individual Reward Networks**: Two strategies for the reward network are tested, all agents in a game share a single reward network or each agent evolves its reward network.



TRAINING: TEACHING AGENTS TO COOPERATE

TRAINING: TEACHING AGENTS TO COOPERATE

- Multi-Agent Reinforcement Learning:Agents learn by doing. They take actions in the environment and learn based on the rewards or penalties they receive. The goal is to maximize their cumulative reward over time.

TRAINING: TEACHING AGENTS TO COOPERATE

- **Multi-Agent Reinforcement Learning**:Agents learn by doing. They take actions in the environment and learn based on the rewards or penalties they receive. The goal is to maximize their cumulative reward over time.
- **Evolutionary Strategy**:Agents are periodically evaluated, and their reward network's parameters are subject to evolution.
    - The best-performing agents (higher rewards) are more likely to reproduce passing their characteristics to the next generation.
    - Over generations, agents with reward networks that lead to beneficial cooperative behavior become more common.

TRAINING: TEACHING AGENTS TO COOPERATE

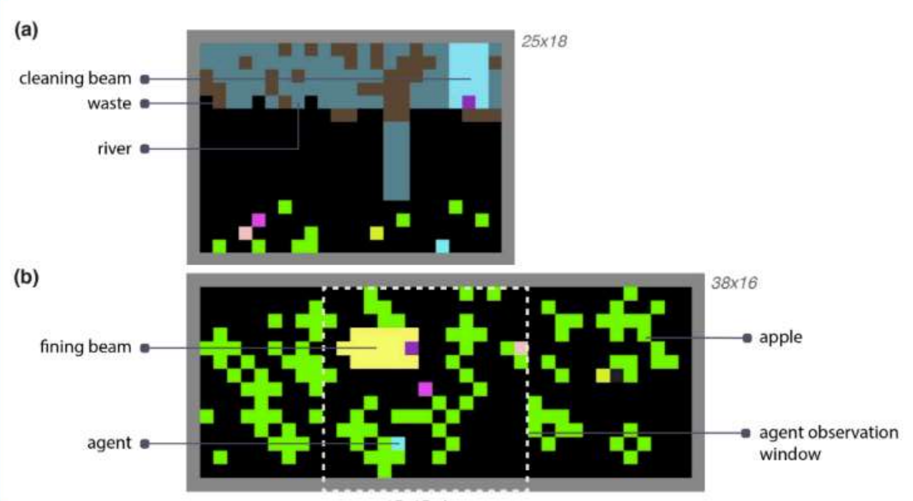
- **Multi-Agent Reinforcement Learning**:Agents learn by doing. They take actions in the environment and learn based on the rewards or penalties they receive. The goal is to maximize their cumulative reward over time.
- **Evolutionary Strategy**:Agents are periodically evaluated, and their reward network's parameters are subject to evolution.
    - The best-performing agents (higher rewards) are more likely to reproduce passing their characteristics to the next generation.
    - Over generations, agents with reward networks that lead to beneficial cooperative behavior become more common.
- **Intertemporal Social Dilemmas (ISDs)**:The environments for training, designed to mimic situations where cooperation is challenging but essential for long-term success. Agents need to learn not just how to maximize immediate rewards but to cooperate for greater future benefits.

TRAINING: TEACHING AGENTS TO COOPERATE

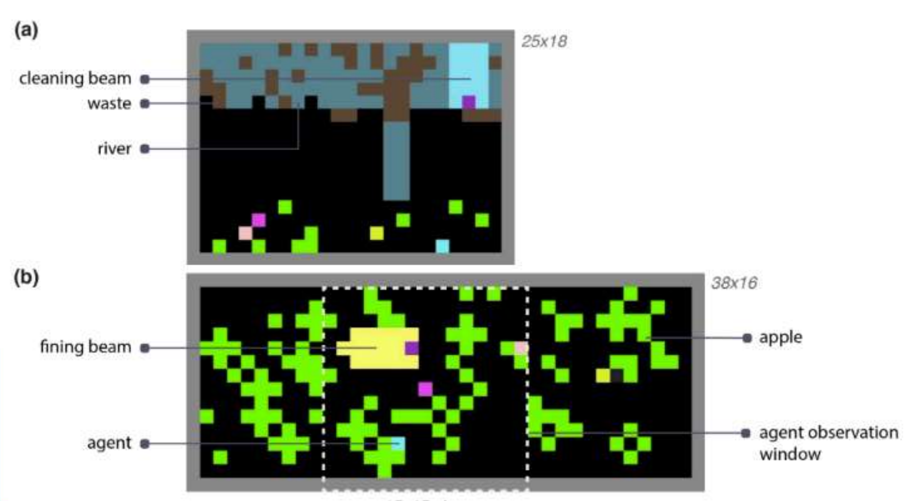
- **Multi-Agent Reinforcement Learning**:Agents learn by doing. They take actions in the environment and learn based on the rewards or penalties they receive. The goal is to maximize their cumulative reward over time.
- **Evolutionary Strategy**:Agents are periodically evaluated, and their reward network's parameters are subject to evolution.
  - The best-performing agents (higher rewards) are more likely to reproduce passing their characteristics to the next generation.
  - Over generations, agents with reward networks that lead to beneficial cooperative behavior become more common.
- **Intertemporal Social Dilemmas (ISDs)**:The environments for training, designed to mimic situations where cooperation is challenging but essential for long-term success. Agents need to learn not just how to maximize immediate rewards but to cooperate for greater future benefits.
- **Intrinsic Motivations**: The reward network is tweaked not just by direct outcomes but by intrinsic motivations (internal goals) that encourage behaviors beneficial to the group, even if they're not immediately rewarding for the individual.

EXPERIMENT ENVIRONMENTS

- Cleanup Game
  - Agents must cooperate to clean a polluted aquifer to ensure the continuous growth of apples. The dilemma arises when individuals must decide whether to clean (contributing to the common good) or collect apples (personal gain), with the collective outcome heavily dependent on group cooperation.
- Harvest Game
  - The challenge is to collect apples without depleting them. The social dilemma surfaces as agents must balance the temptation to harvest apples rapidly for immediate reward against the sustainable management of resources, ensuring long-term availability for all.



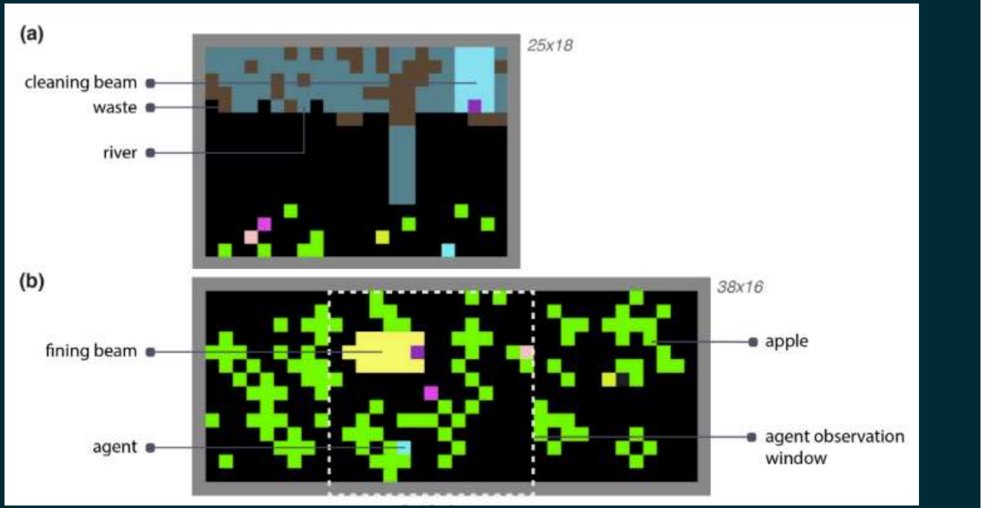
- Cleanup Game
  - Agents must cooperate to clean a polluted aquifer to ensure the continuous growth of apples. The dilemma arises when individuals must decide whether to clean (contributing to the common good) or collect apples (personal gain), with the collective outcome heavily dependent on group cooperation.
- Harvest Game
  - The challenge is to collect apples without depleting them. The social dilemma surfaces as agents must balance the temptation to harvest apples rapidly for immediate reward against the sustainable management of resources, ensuring long-term availability for all.

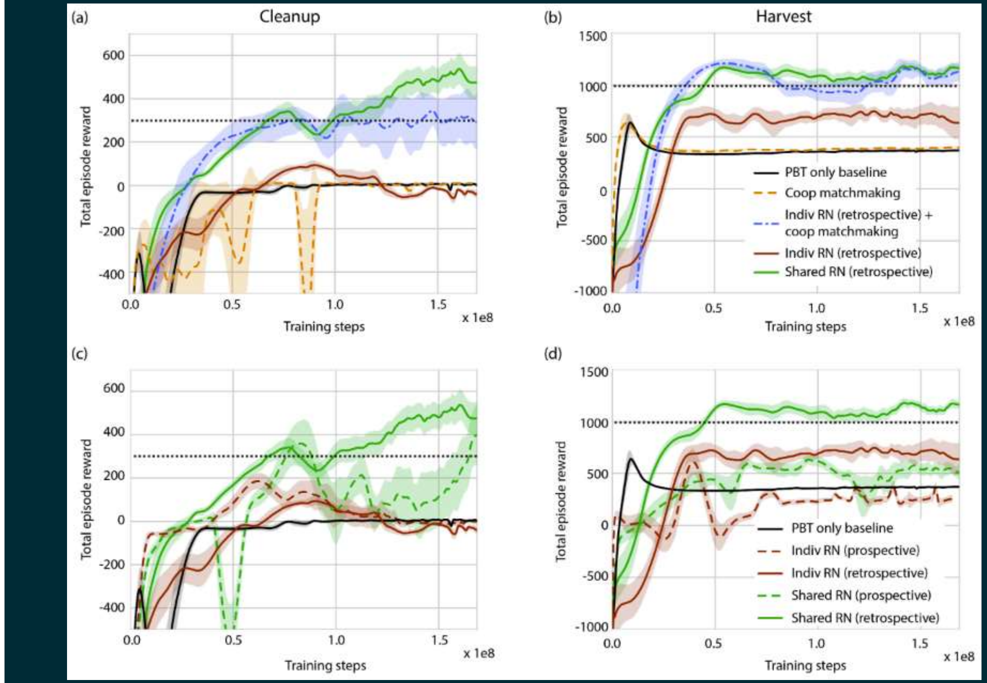


EXPERIMENT ENVIRONMENTS

EXPERIMENT ENVIRONMENTS

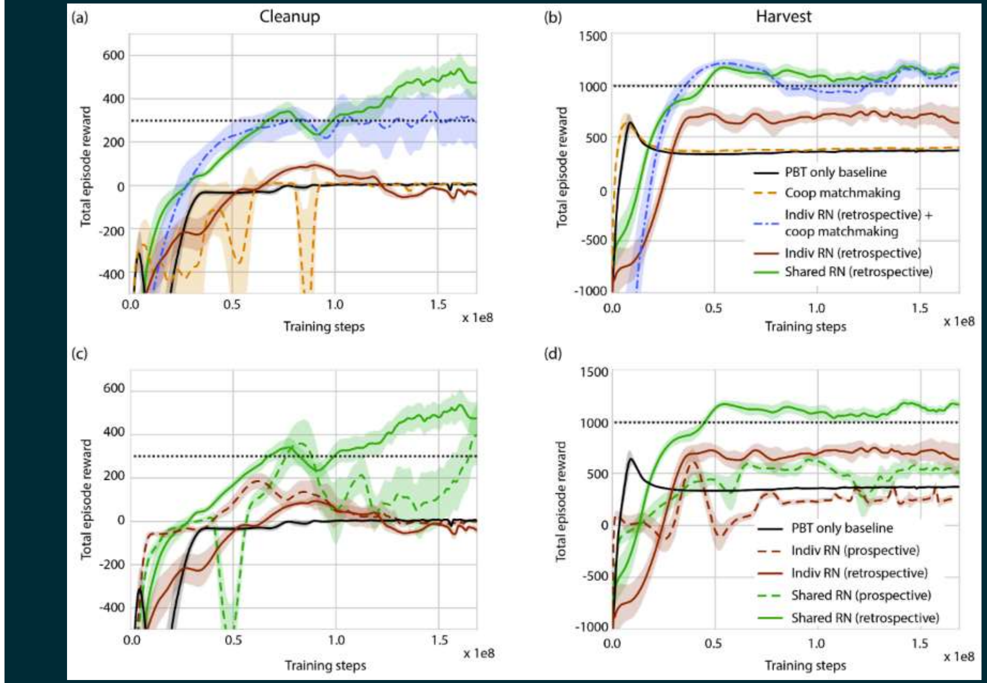
- Cleanup Game
  - Agents must cooperate to clean a polluted aquifer to ensure the continuous growth of apples. The dilemma arises when individuals must decide whether to clean (contributing to the common good) or collect apples (personal gain), with the collective outcome heavily dependent on group cooperation.
- Harvest Game
  - The challenge is to collect apples without depleting them. The social dilemma surfaces as agents must balance the temptation to harvest apples rapidly (for immediate reward) against the sustainable management of resources, ensuring long-term availability for all.



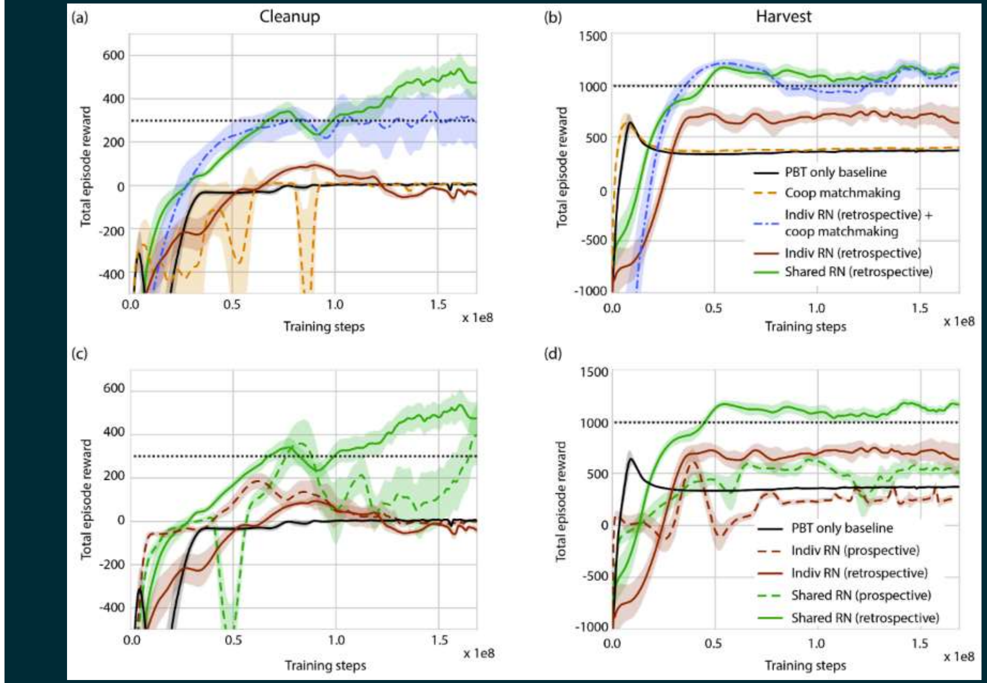


RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING

RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING

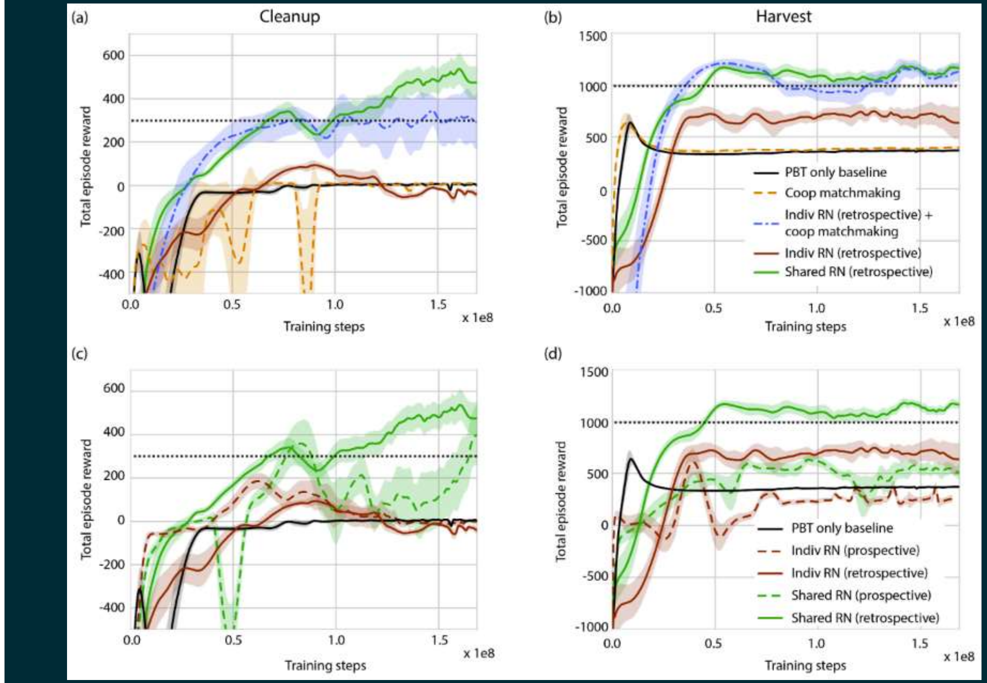


- (Baseline) Without using intrinsic reward network performs poorly on both games.



- (Baseline) Without using intrinsic reward network performs poorly on both games.
- Using Random Matchmaking + Individual Retrospective Reward Network, no better than PBT at Cleanup and moderately better at Harvest

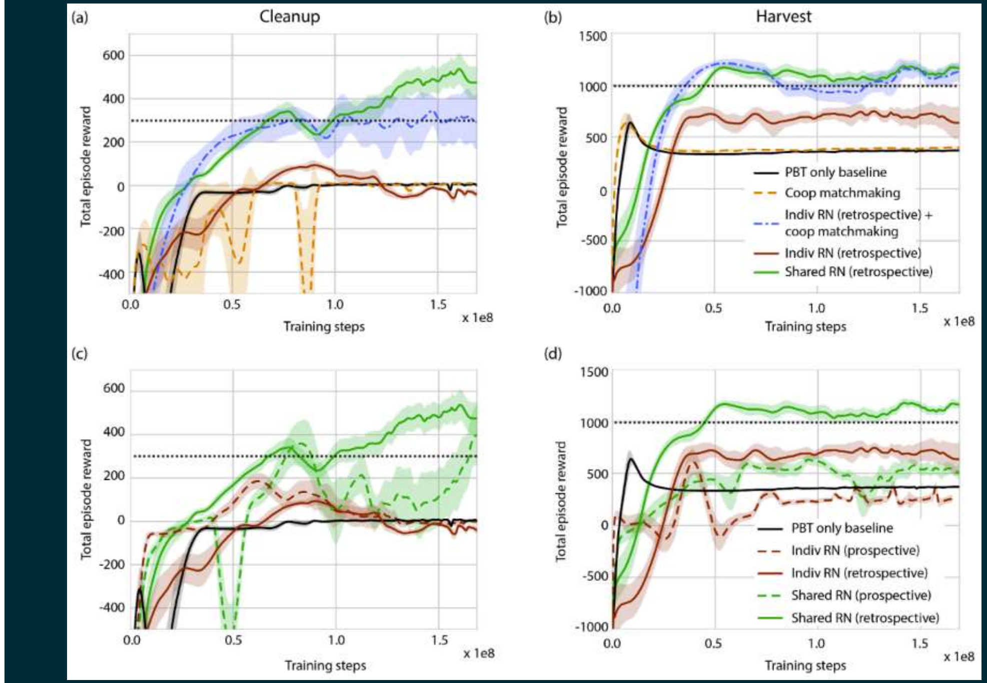
RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING



- (Baseline) Without using intrinsic reward network performs poorly on both games.
- Using Random Matchmaking + Individual Retrospective Reward Network, no better than PBT at Cleanup and moderately better at Harvest
- Using Assortative Matchmaking + No Reward Network, performance is same as baseline.

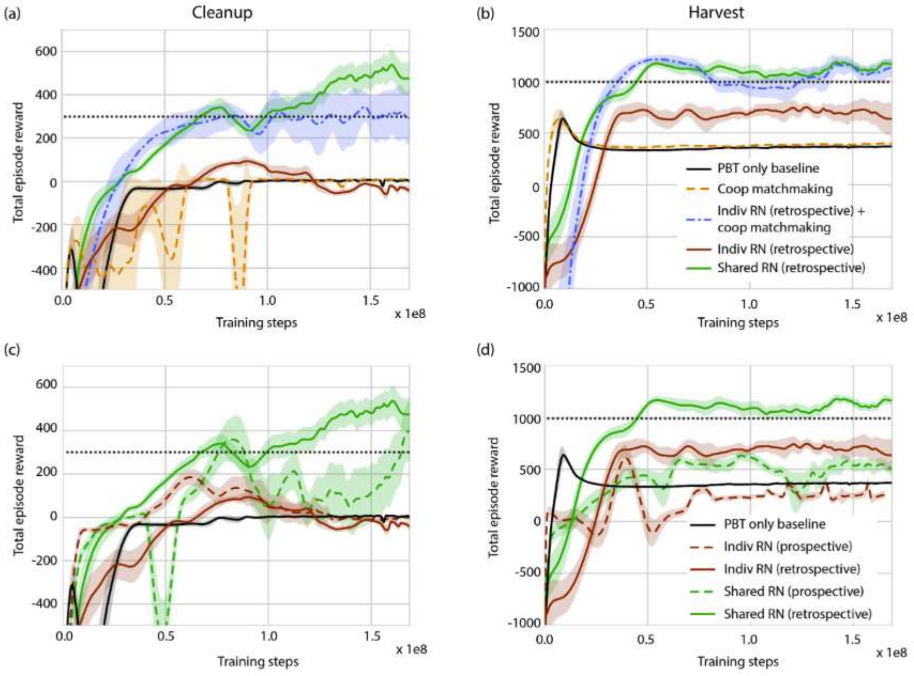
RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING

RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING



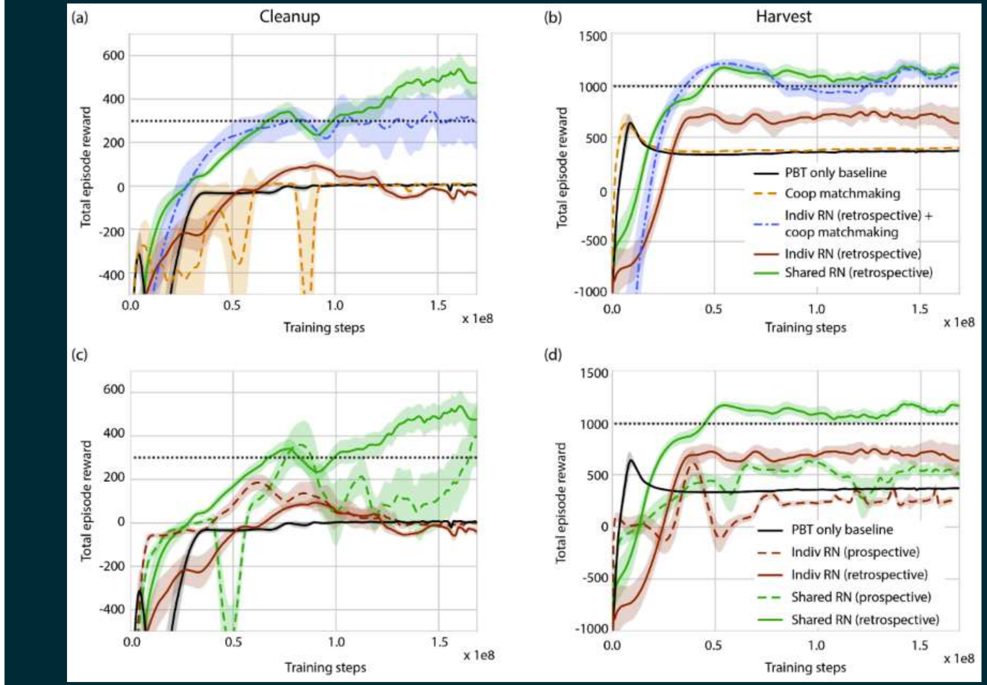
- (Baseline) Without using intrinsic reward network performs poorly on both games.
- Using Random Matchmaking + Individual Retrospective Reward Network, no better than PBT at Cleanup and moderately better at Harvest
- Using Assortative Matchmaking + No Reward Network, performance is same as baseline.
- Using Assortative Matchmaking + Individual Retrospective Reward Network, performance is very high.

RESULTS: RANDOM VS. ASSORTATIVE MATCHMAKING

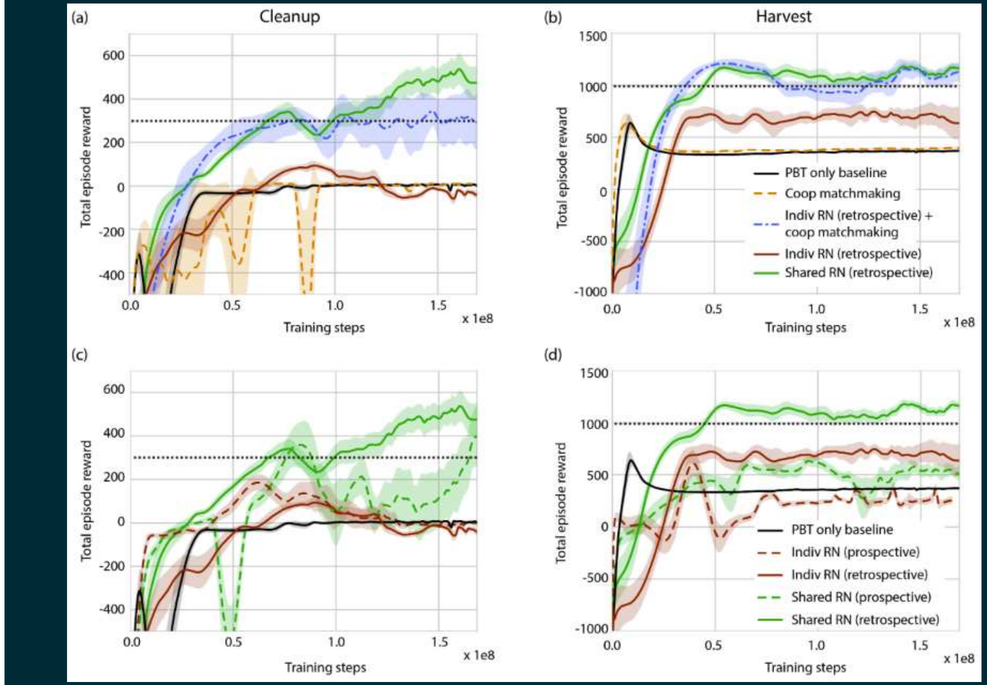


- (Baseline) Without using intrinsic reward network performs poorly on both games.
- Using Random Matchmaking + Individual Retrospective Reward Network, no better than PBT at Cleanup and moderately better at Harvest
- Using Assortative Matchmaking + No Reward Network, performance is same as baseline.
- Using Assortative Matchmaking + Individual Retrospective Reward Network, performance is very high.
- Using Random Matchmaking + Shared Retrospective Reward Network performs as well as AM+IRRN in Harvest, and slightly better for Cleanup.

RESULTS: PROSPECTIVE VS RETROSPECTIVE REWARD NETWORK

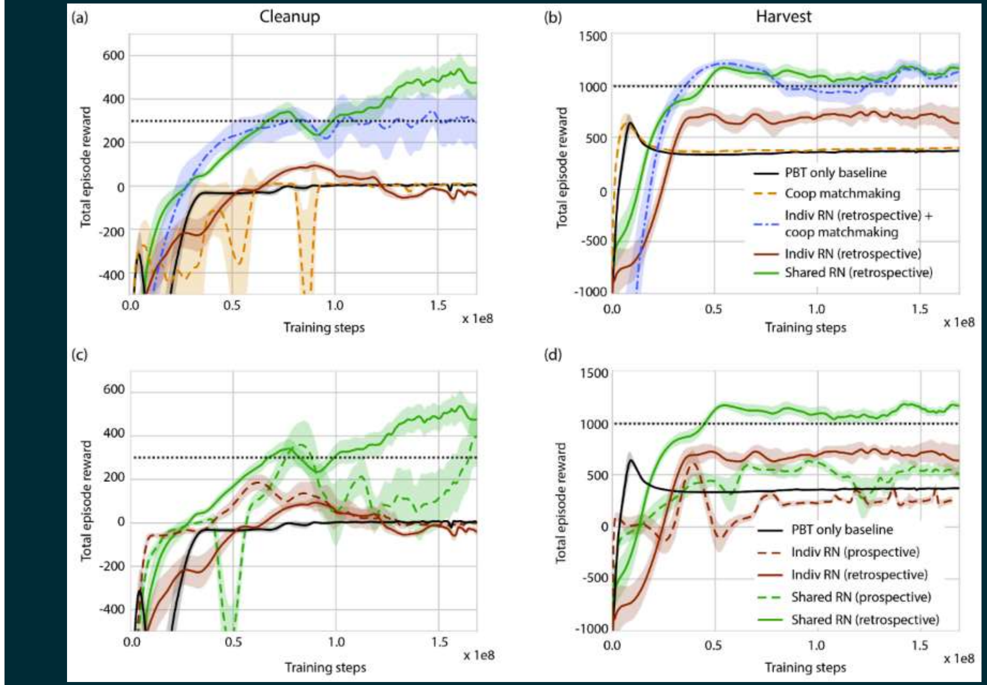


RESULTS: PROSPECTIVE VS RETROSPECTIVE REWARD NETWORK



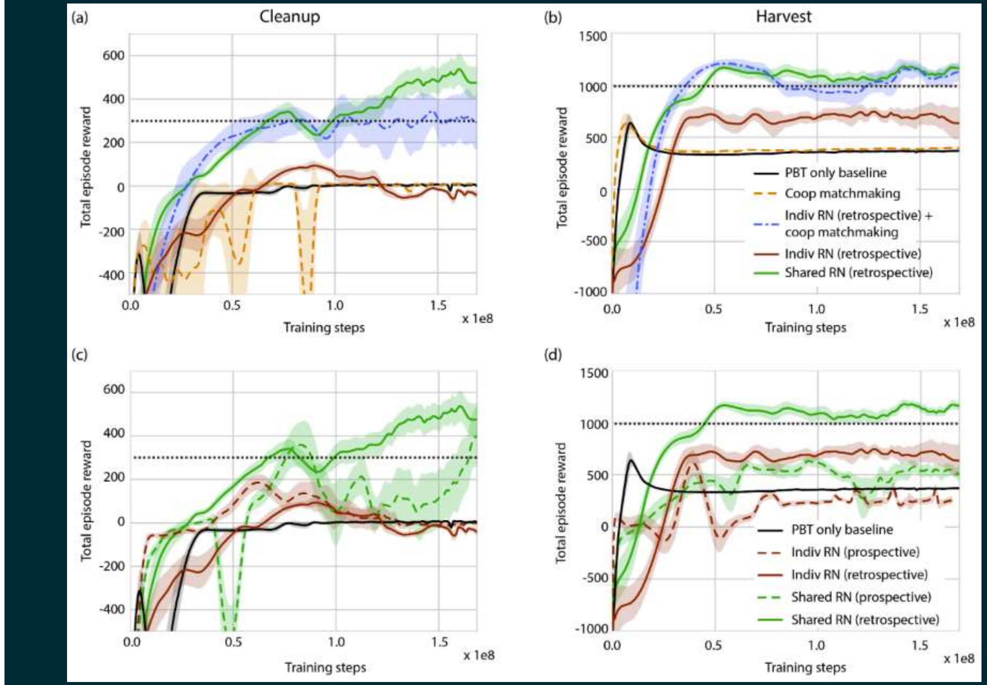
- Using Individual Prospectivepective Reward Network, performance is slightly worse than baseline for both games.

RESULTS: PROSPECTIVE VS RETROSPECTIVE REWARD NETWORK



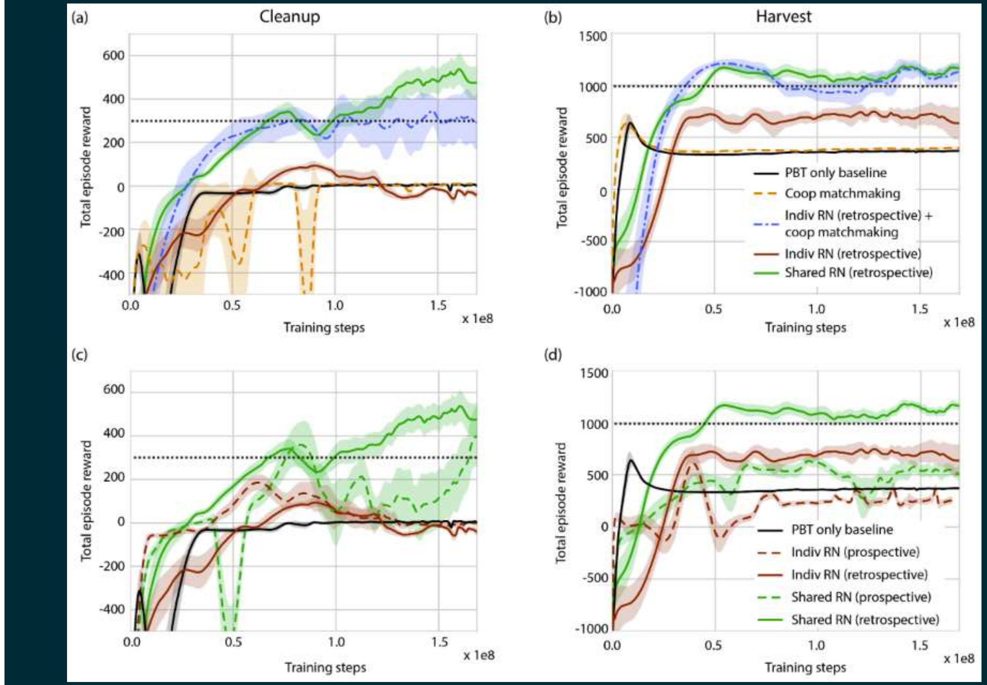
- Using Individual Prospectivepective Reward Network, performance is slightly worse than baseline for both games.
- Using Individual Retrospective Reward Network, no better than baseline at Cleanup and moderately better at Harvest

RESULTS: PROSPECTIVE VS RETROSPECTIVE REWARD NETWORK

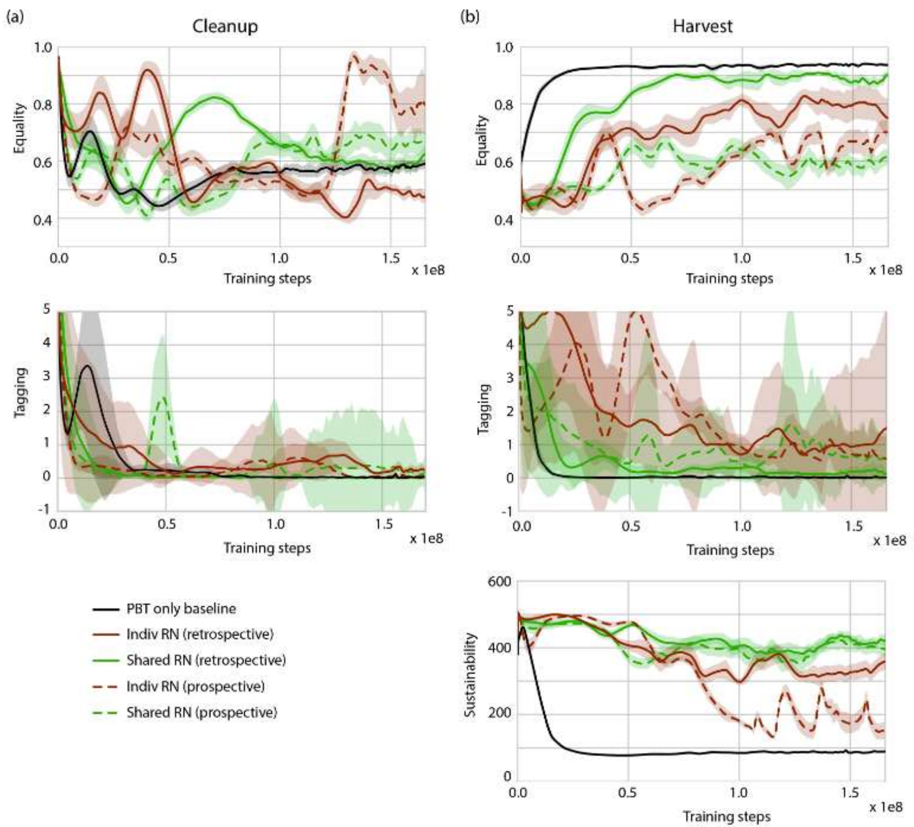


- Using Individual Prospectivepective Reward Network, performance is slightly worse than baseline for both games.
- Using Individual Retrospective Reward Network, no better than baseline at Cleanup and moderately better at Harvest
- Using Shared Prospective Reward Network, although better than baseline, generally results in worse performance and more inestability.

RESULTS: PROSPECTIVE VS RETROSPECTIVE REWARD NETWORK



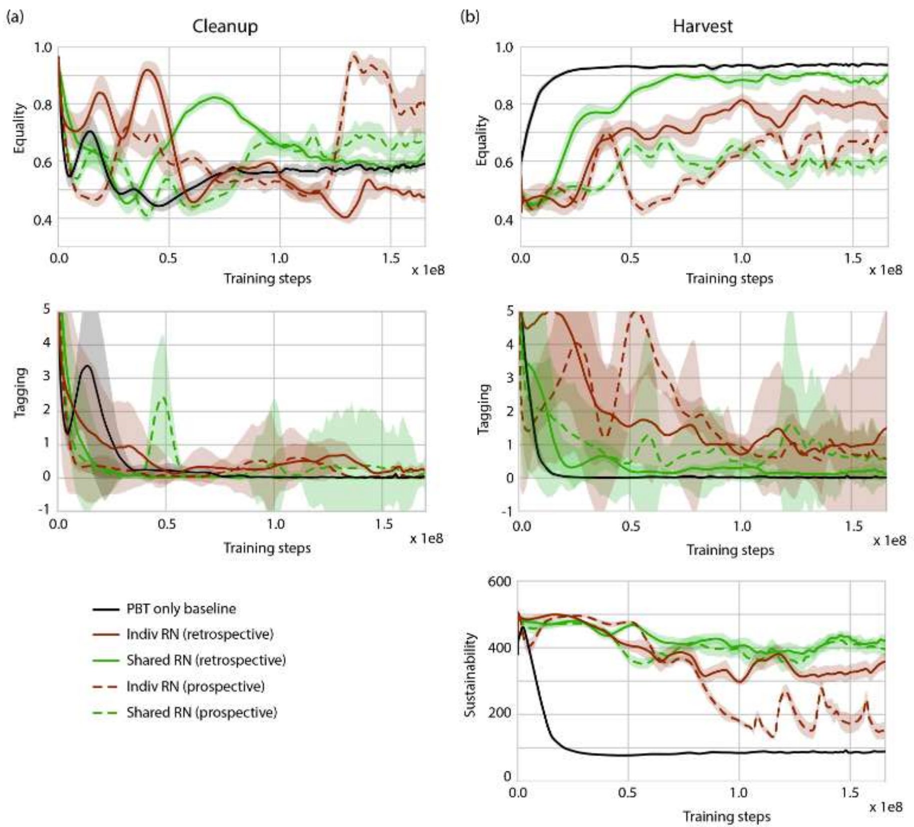
- Using Individual Prospectivepective Reward Network, performance is slightly worse than baseline for both games.
- Using Individual Retrospective Reward Network, no better than baseline at Cleanup and moderately better at Harvest
- Using Shared Prospective Reward Network, although better than baseline, generally results in worse performance and more inestability.
- Using Shared Prospective Reward Network, better performance and more estability.



- [illegible]
  - [illegible]
  - [illegible]
  - [illegible]
- [illegible]
  - [illegible]
  - [illegible]
  - [illegible]

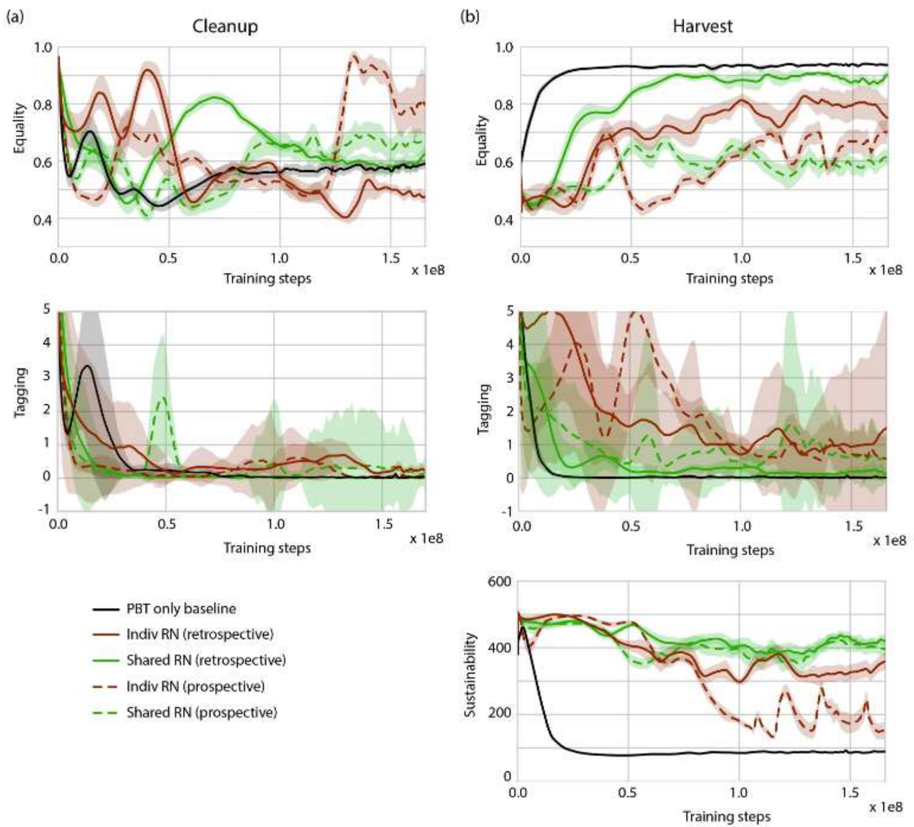
RESULTS: SOCIAL OUTCOME METRICS

RESULTS: SOCIAL OUTCOME METRICS



- In Harvest:
  - Prospectivepective RN leads to a lower equality, Restrospective RN tends to very high equality.
  - Higher propensity for tagging when using either a Prospective RN or an Individual RN, than when using a Retrospective Shared RN.
  - Having No RN results in players collecting apples extremely quickly, compared with much more sustainable behavior With RN.
- [illegible]
  - [illegible]
  - [illegible]
  - [illegible]

RESULTS: SOCIAL OUTCOME METRICS



- **In Harvest:**
  - Prospectivepective RN leads to a lower equality, Restrospective RN tends to very high equality.
  - Higher propensity for tagging when using either a Prospective RN or an Individual RN, than when using a Retrospective Shared RN.
  - Having No RN results in players collecting apples extremely quickly, compared with much more sustainable behavior With RN.
- **In Cleanup:**
  - Tends to a unstable and low overall equality even when performance is high.
  - The use of tagging by agents is overall much more lower than in Harvest.
  - No meaningful were obtained for Sustainability.

CONCLUSIONS

CONCLUSIONS

- As stated by the evolutionary theory, only via natural selection does not leads to the emergence of cooperation.

CONCLUSIONS

- As stated by the evolutionary theory, only via natural selection does not leads to the emergence of cooperation.
- Assortative Matchmaking is sufficient to generate cooperative behavior where signals of reward (intrinsic reward) are available.

CONCLUSIONS

- As stated by the evolutionary theory, only via natural selection does not leads to the emergence of cooperation.
- Assortative Matchmaking is sufficient to generate cooperative behavior where signals of reward (intrinsic reward) are available.
- The proposed multi-level evolutionary paradigm achieve cooperation in more general situations.

CONCLUSIONS

- As stated by the evolutionary theory, only via natural selection does not leads to the emergence of cooperation.
- Assortative Matchmaking is sufficient to generate cooperative behavior where signals of reward (intrinsic reward) are available.
- The proposed multi-level evolutionary paradigm achieve cooperation in more general situations.
- Evolution bridges the gap between individual learning and long-term group benefits, enhancing cooperation by revealing social signals related to selfish behavior, that contributes to the resolution of the intertemporal social dilemmas. In accord, laboratory experiments show that humans cooperate more readily when they can communicate.