Pathfinding and Routing
NAIL137

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Centralized approach

- So far…
  - There is a central coordination agent
  - All moving agents obey
- Challenges
  - Communication
  - Synchronization
  - Computation resources
  - No outside influence

Decentralized approach

- Each agent acts with its own interest
- Challenges
  - Requires sensing
  - Can not be optimal
  - Needs to avoid deadlocks/livelocks

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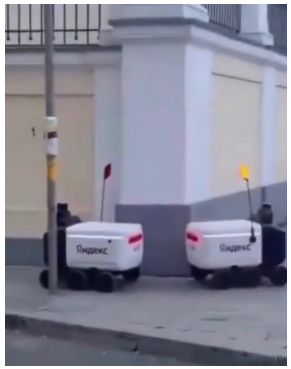
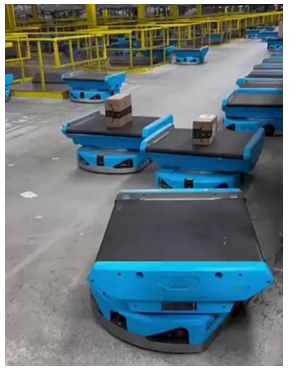


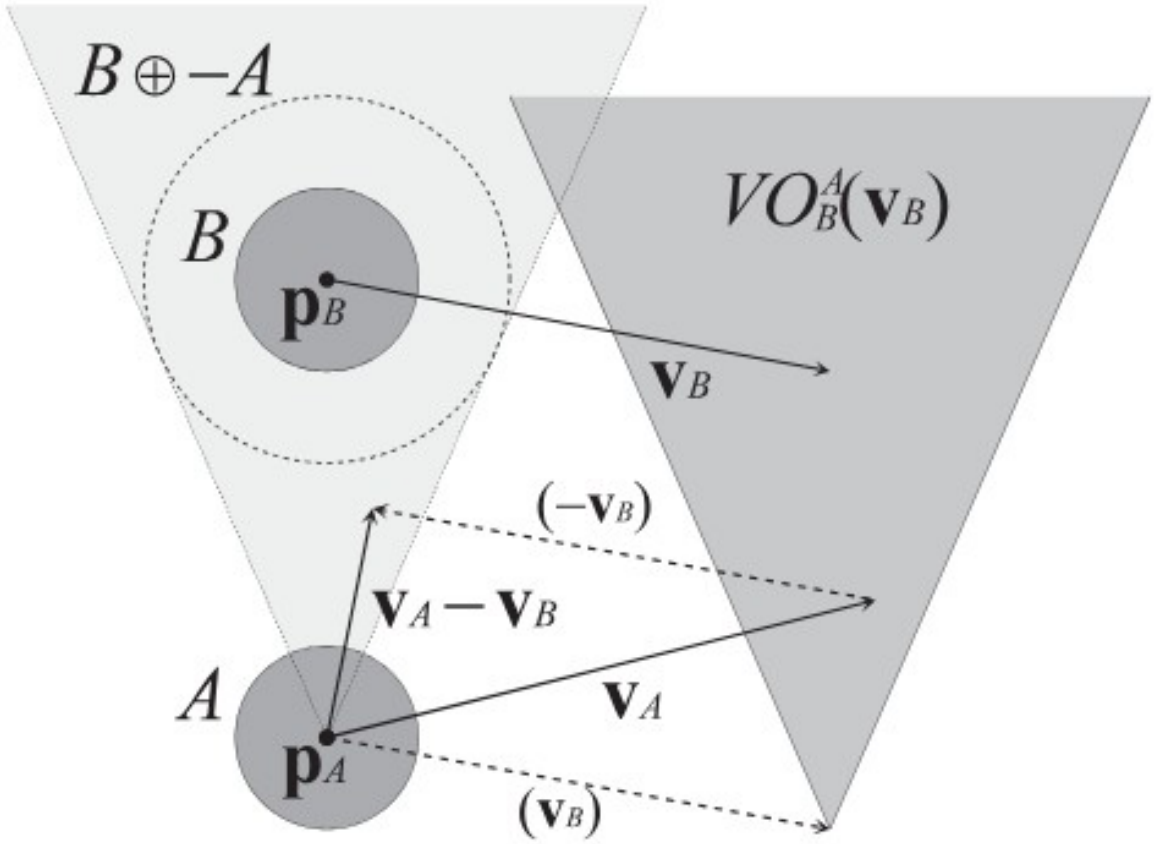


General approach

- A greedy path is known
- Each agent has a policy (i.e. set of rules)
  - Current state → action
- Actions aim to avoid collisions and navigate towards goal
- Rules can be hand-made or learned

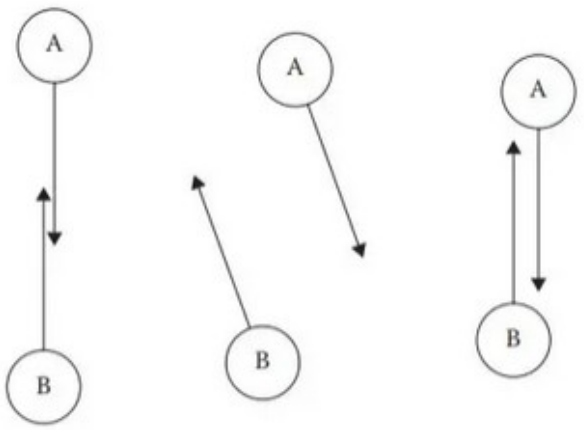
ORCA

- Velocity Obstacle (VO)



ORCA

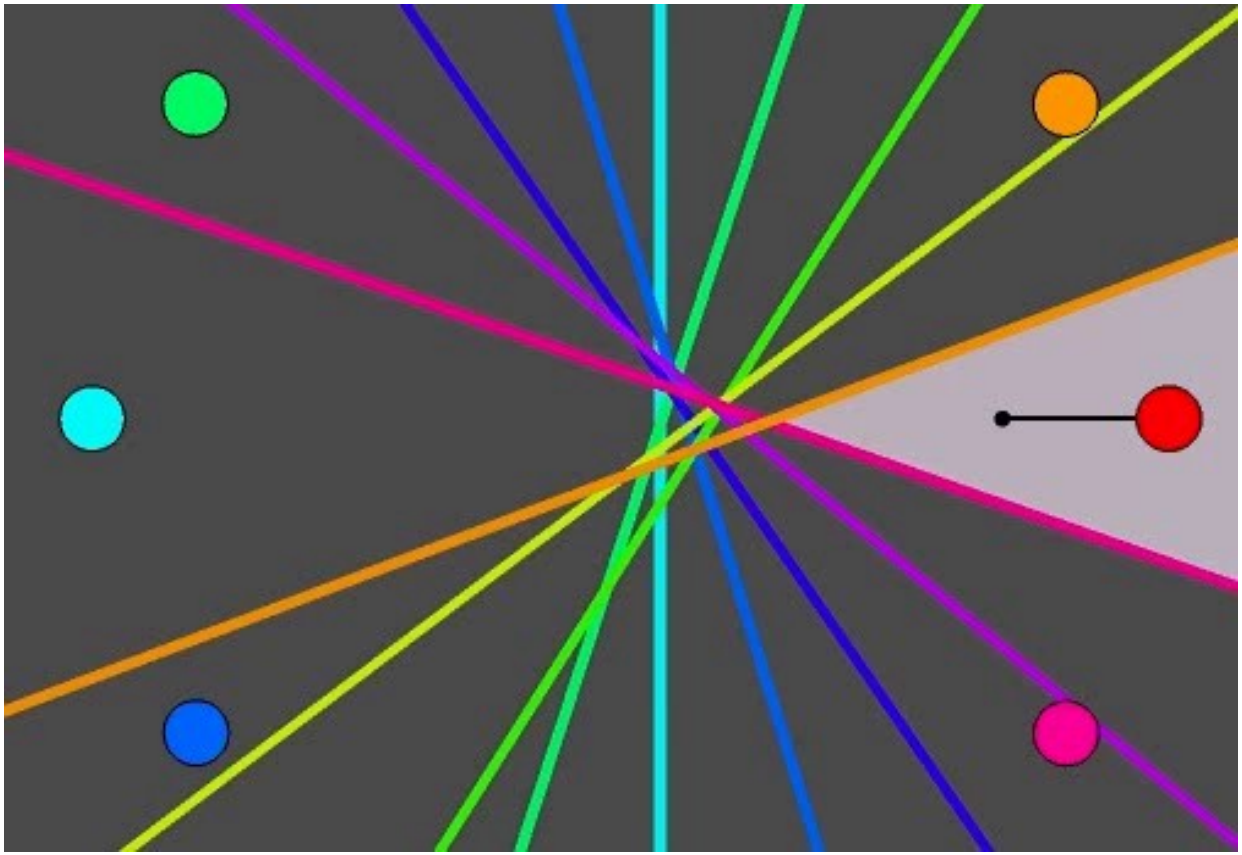
- Problem with VO is jitter



- Reciprocal Velocity Obstacle (RVO)
  - Both agents take responsibility
  - Both agents know they follow the same rules

ORCA

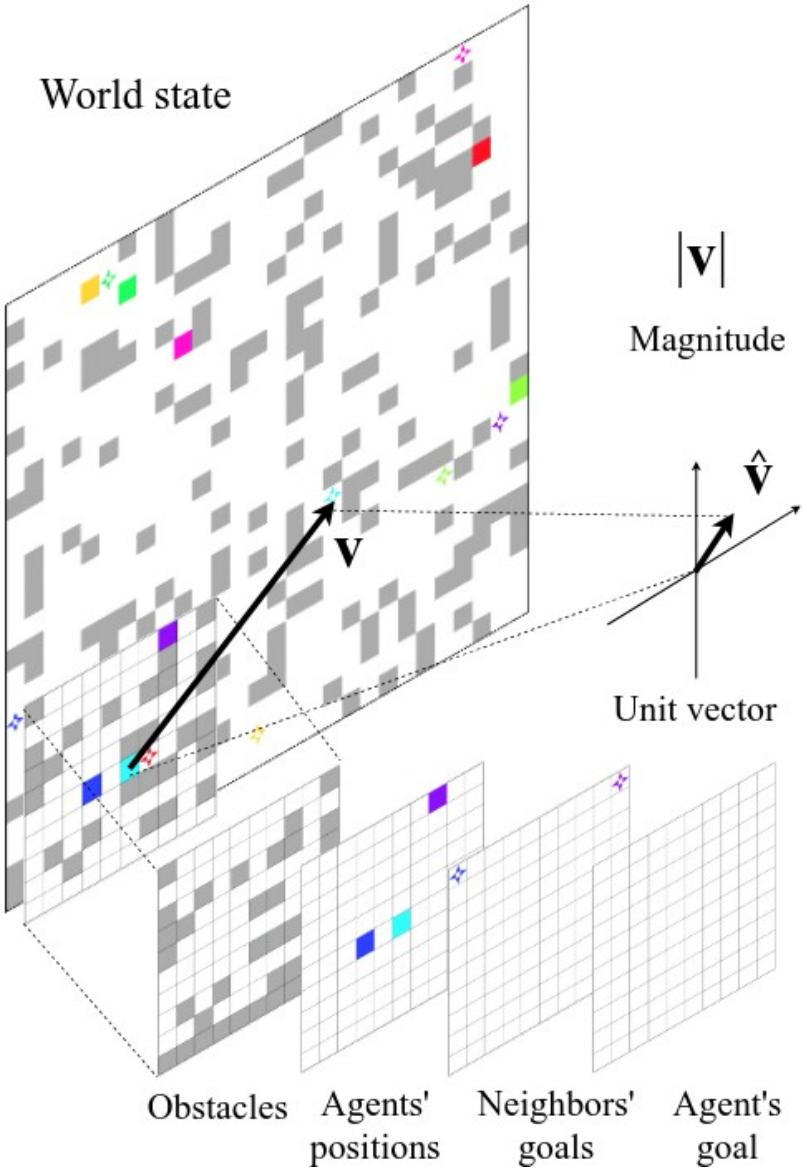
- Optimal Reciprocal Collision Avoidance
  - Can deal with multiple agents at once



J. van den Berg, S. Guy, M. Lin, D. Manocha. Reciprocal n-Body Collision Avoidance. ISRR, 2009.

Primal

- ML approach
- Decentralized
- Local observation



G. Sartoretti, J. Kerr, Y. Shi, G. Wagner, S. Kumar, S. Koenig, H. Choset. PRIMAL: Pathfinding via Reinforcement and Imitation Multi-Agent Learning. IEEE Robotics Autom. Lett., 2019

Primal - NN structure

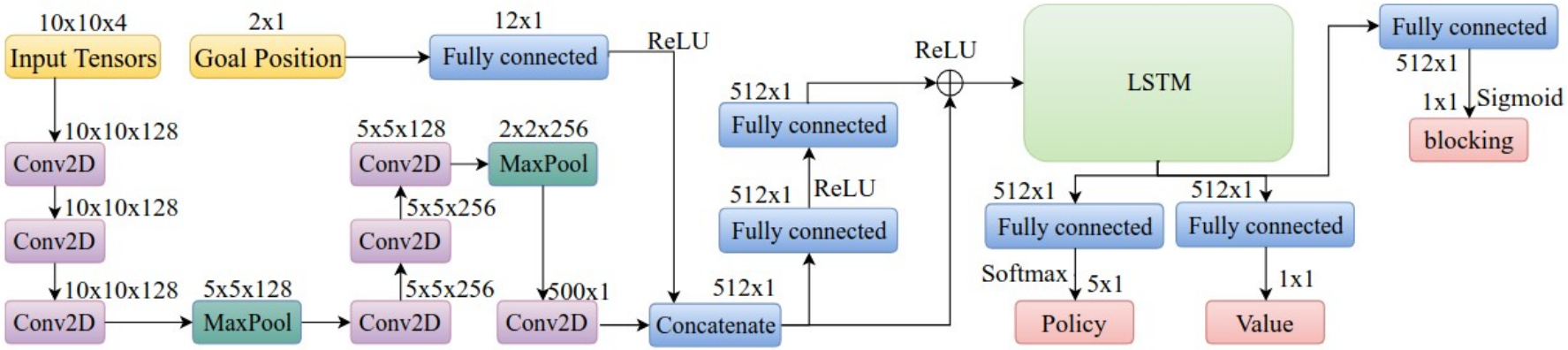


Fig. 3. The neural network consists of 7 convolutional layers interleaved with maxpooling layers, followed by an LSTM.

Primal - learning

- Initial approach

SIMPLE REWARD STRUCTURE.

Action	Reward
Move [N/E/S/W]	-0.3
Agent Collision	-2.0
No Movement (on/off goal)	0.0 / -0.5
Finish Episode	+20.0

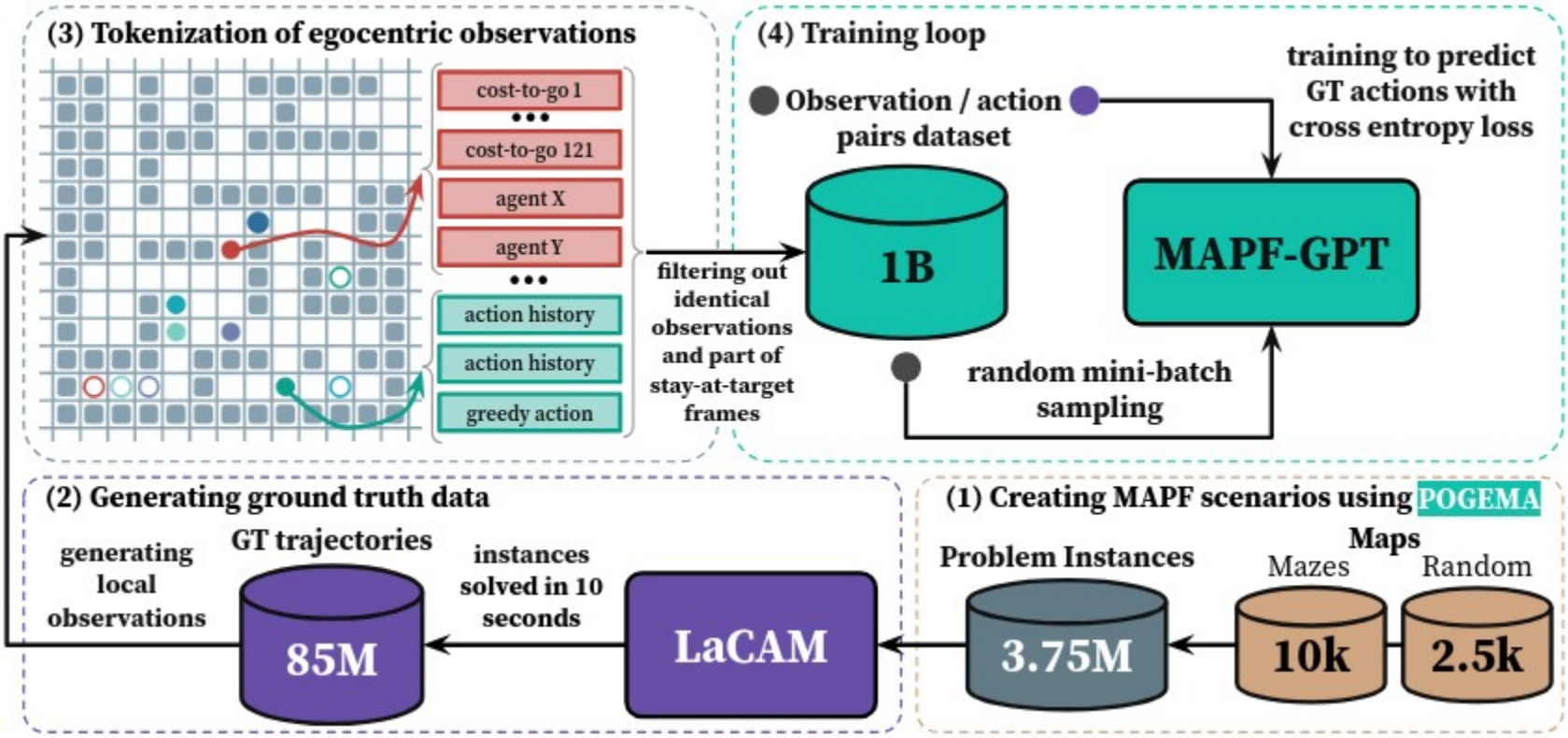
- Make decentralized agents act selflessly
  - Blocking penalty
  - Imitation learning
  - Custom cluttered scenarios

Imitation learning

1) Collect ground truth from expert solver
2) Supervised learning aiming to mimic expert

- Aim is to improve scalability
- Combined with reinforcement learning and curriculum learning might outperform expert

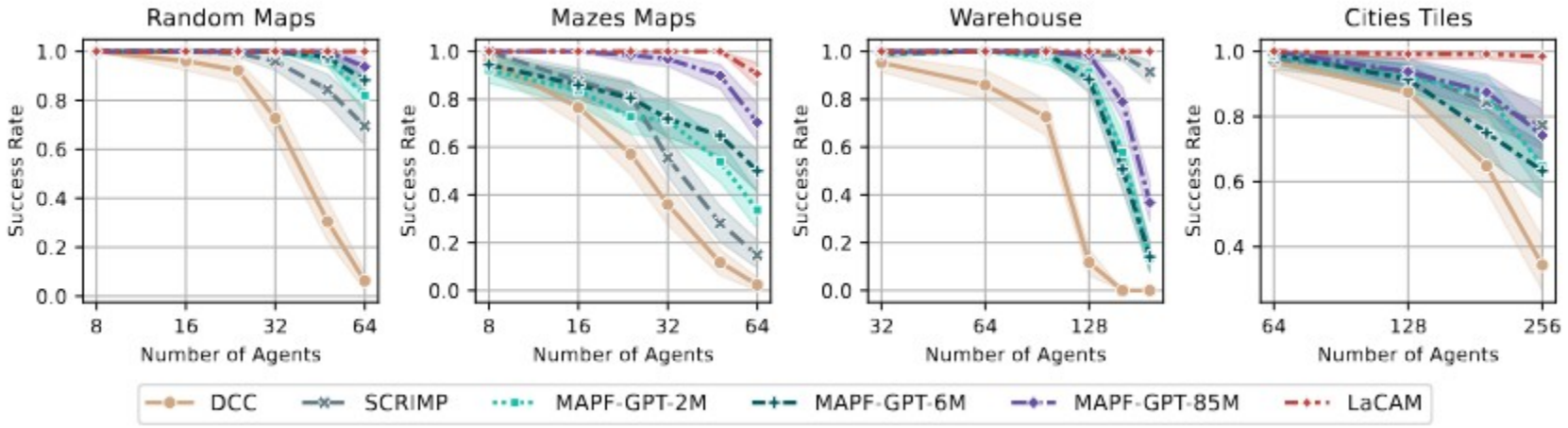
MAPF-GPT



A. Andreychuk, K. Yakovlev, A. Panov, A. Skrynnik. MAPF-GPT: Imitation Learning for Multi-Agent Pathfinding at Scale. AAAI, 2025.

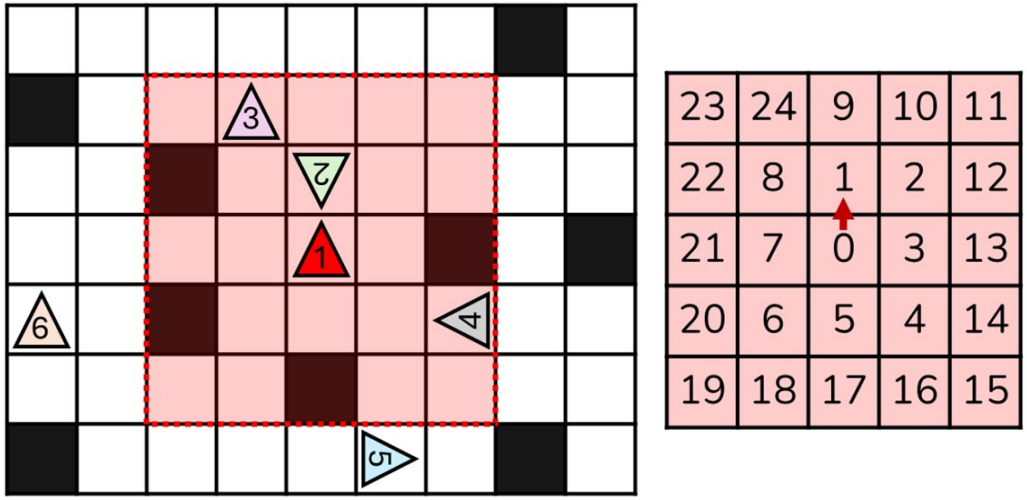
MAPF-GPT

- Does not work well yet!



Social rules

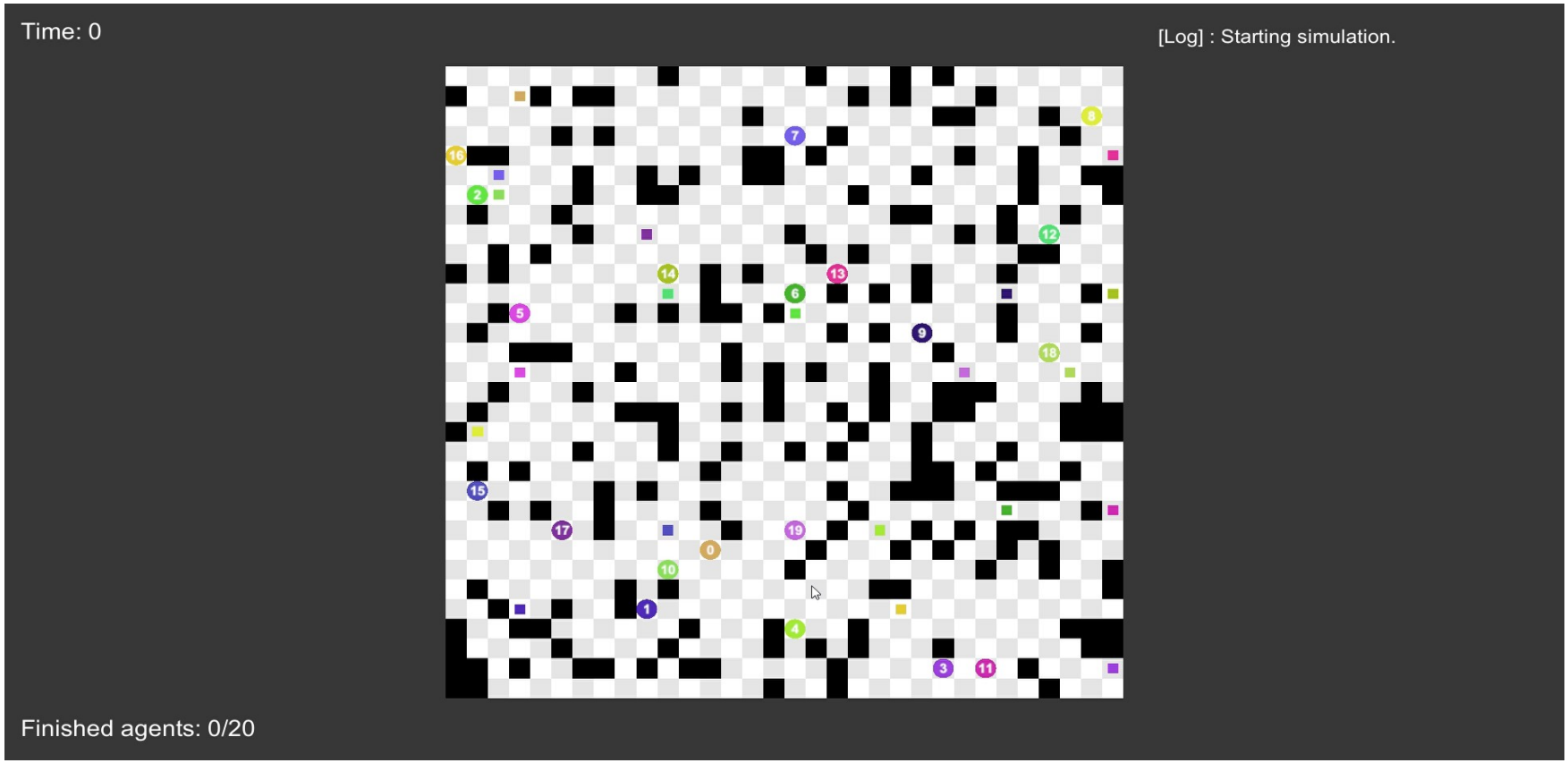
- Like traffic rules when there are no signs
- Hand made
  - Deterministic
  - Stochastic
- Learned?



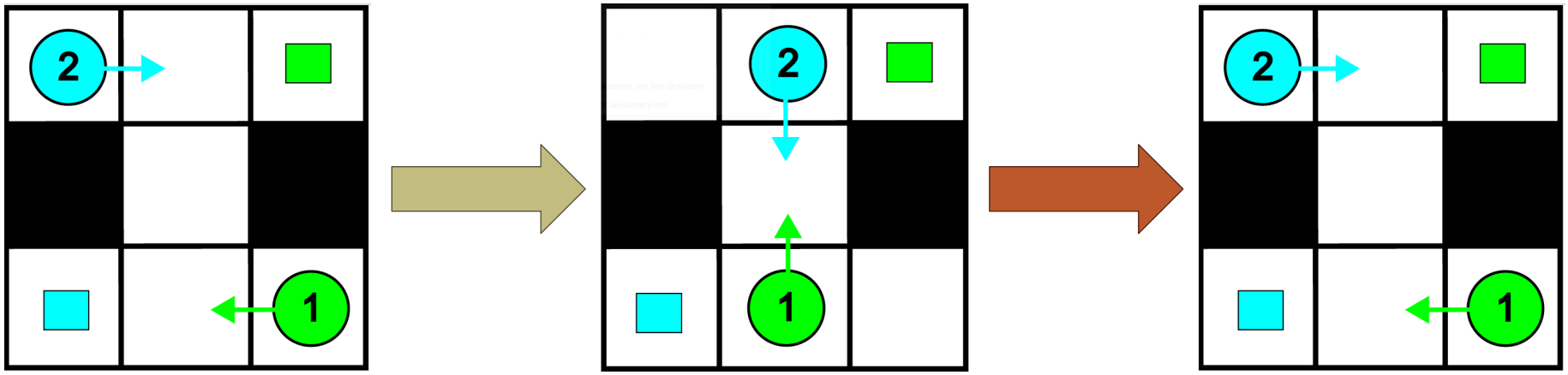
(A1) (N3) (P3) (N4) (N13) -> (R100)

J. Slezák, J. Mestek, R. Barták. Social Laws for Multi-Agent Pathfinding. ICAART, 2025.

Social rules

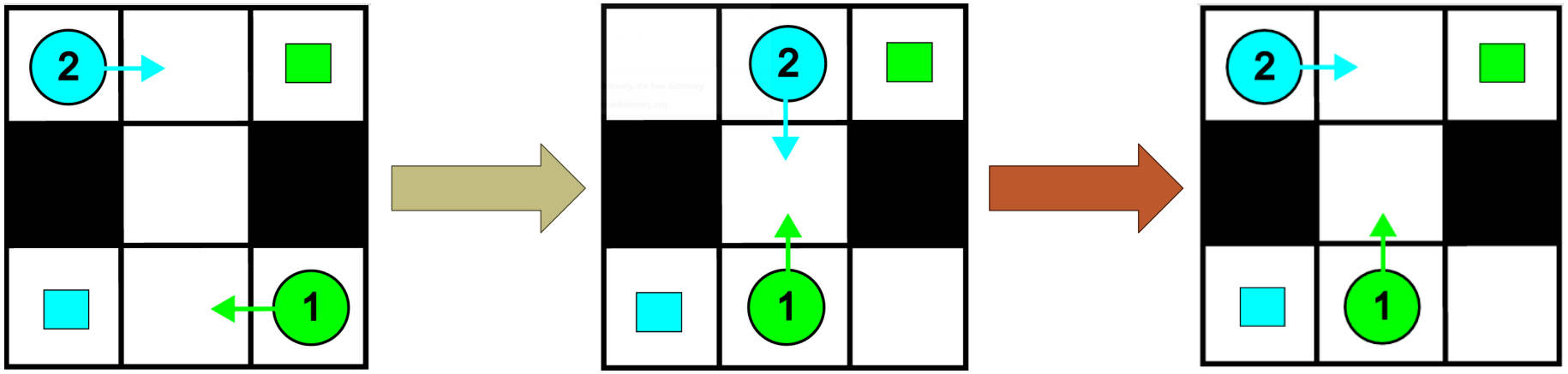


Social rules - resolve deadlocks

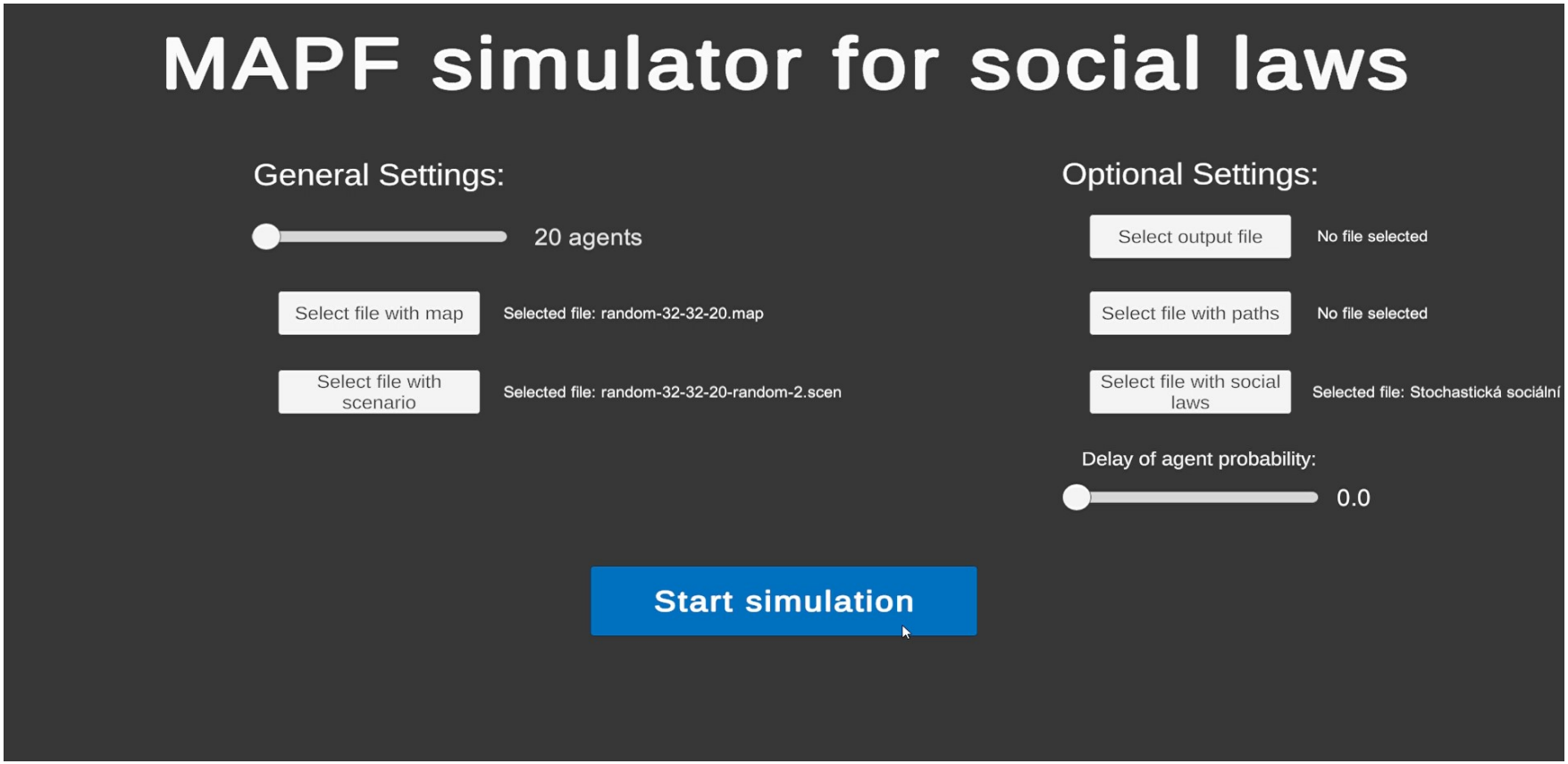


Stochastic social law:

1: (A1) (N3) (P3) (N4) (N13) > (R50) (S50)
2: (A1) (N5) (P5) (N6) (N17) > (B50) (S50)
3: (A1) (N7) (P7) (N8) (N21) > (L50) (S50)

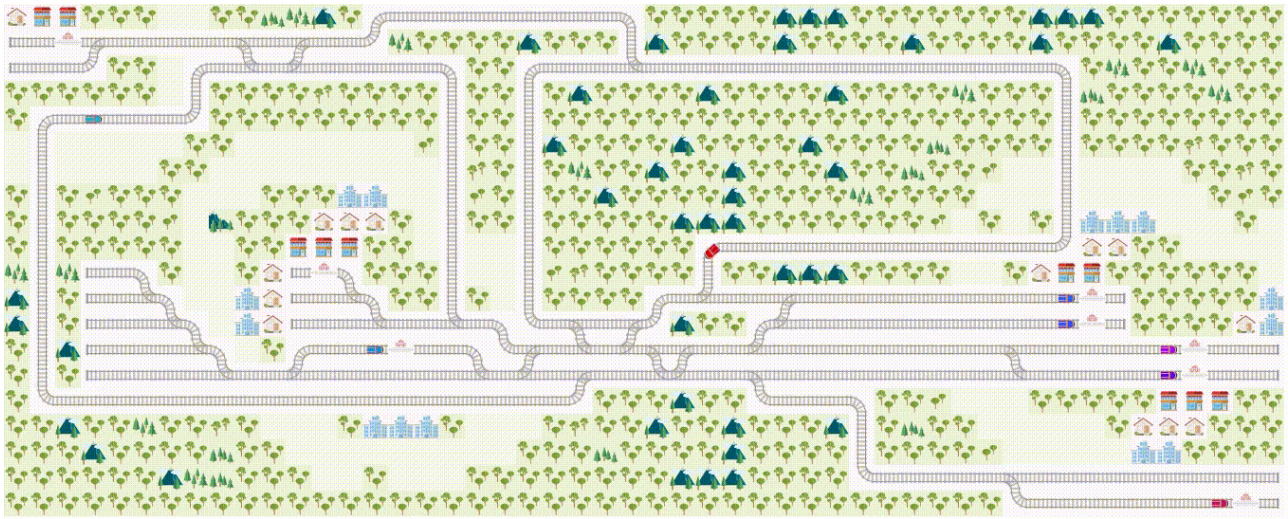


Social rules



Comparing ML and classic approach

- So far, ML techniques fall behind
  - Expensive training
  - Poor scaling
  - Can not handle complicated situations
- Was seen in Flatland challenge

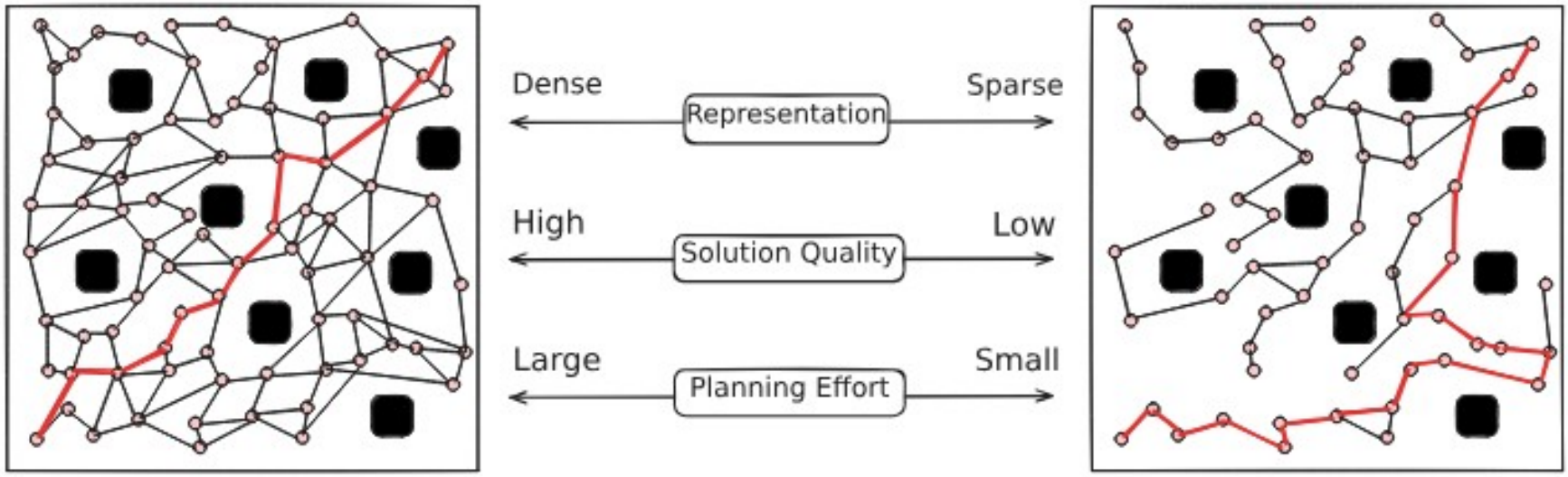


Other ML applications in MAPF

- Environment representation
- Algorithm selection
- Augment existing solver

Environment representation

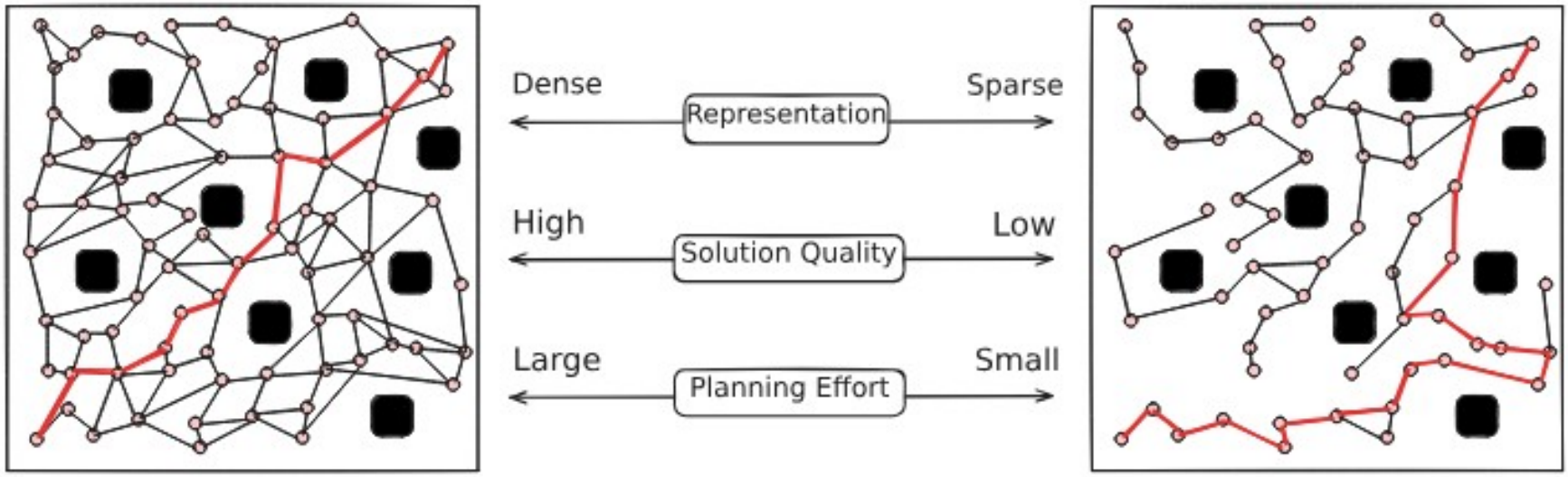
- General optimization scheme
  1) Sample vertices
  2) Create edges
  3) Minimize custom cost function



Environment representation

- General optimization scheme
  1) Sample vertices
  2) Create edges
  3) Minimize custom cost function

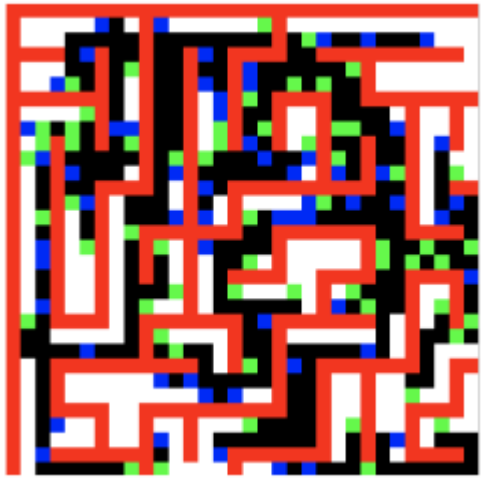
Identify critical locations for collision avoidance



F. Arias, B. Ichter, A. Faust, N. Amato. Avoidance Critical Probabilistic Roadmaps for Motion Planning in Dynamic Environments. ICRA, 2021.

Algorithm selection

- Decide what algorithm to use on given instance
- The hard part is to decide what makes the instance hard
  - Map size
  - Obstacle density
  - Agent density
  - Agent placement
  - ...



J. Ren, V. Sathiyanarayanan, E. Ewing, B. Senbaslar, N. Ayanian. MAPFAST: A Deep Algorithm Selector for Multi Agent Path Finding using Shortest Path Embeddings. AAMAS, 2021.

Augment solvers with ML

- CBS
  - Conflict selection
- EECBS
  - Heuristic functions for top level
- PP
  - Priority selection
- LNS
  - Select neighborhoods