Multi-agent path finding

Team 2 - Dan Vi Trinh, Alex Brown

Motivation

- Warehouse automation
- Drone swarms
- Autonomous traffic management

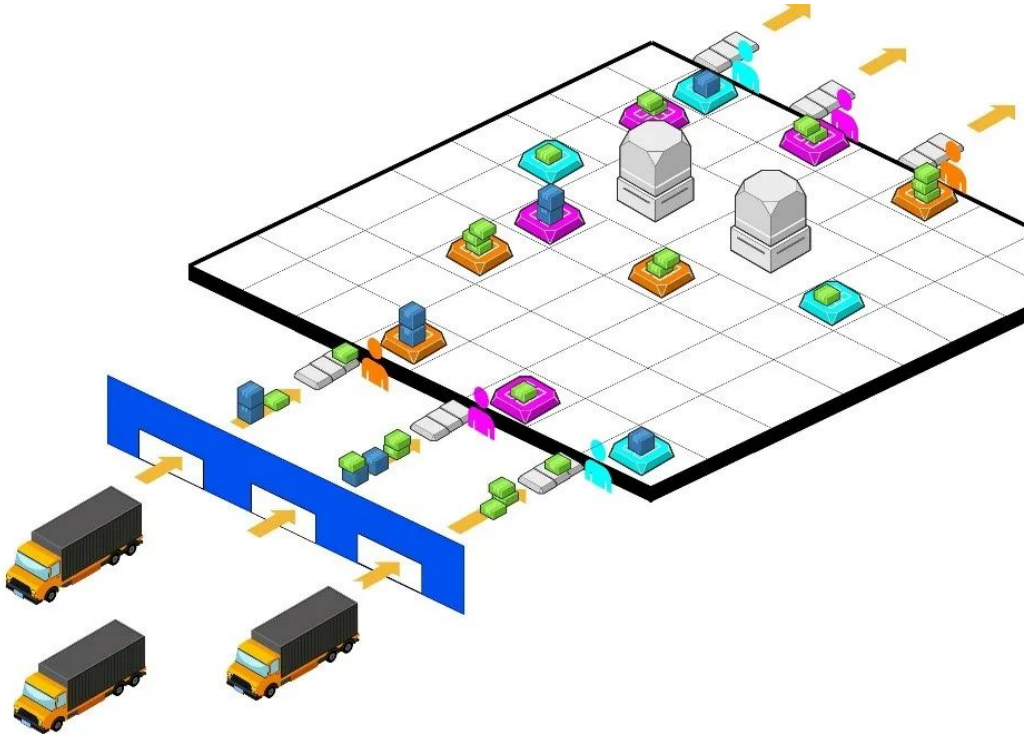


Image source:
https://medium.com/data-reply-it-datatech/multi-agent-pathfinding-ilp-moving-warehouse-robots-with-integer-linear-programming-bb445f78ba4e

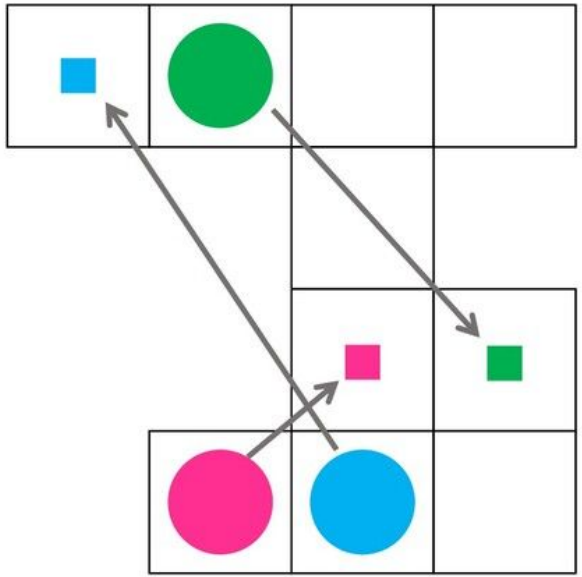
Overview

- Problem statement
- Learning based approach
- Search-based approach
- Optimization-based approach

Multi-agent Path Finding (MAPF)

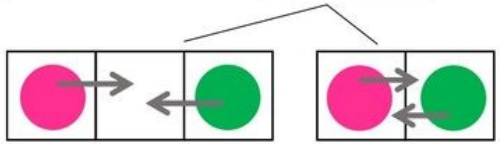
given

- graph
- agents (starts)
- goals



obtain

1. paths without collisions



s.t.

all agents are on their goals **simultaneously**

computationally **DIFFICULT** to obtain optimal solutions

Image source:
https://speakerdeck.com/kei18/priority-inheritance-with-backtracking-for-iterative-multi-agent-path-finding

Conflicts

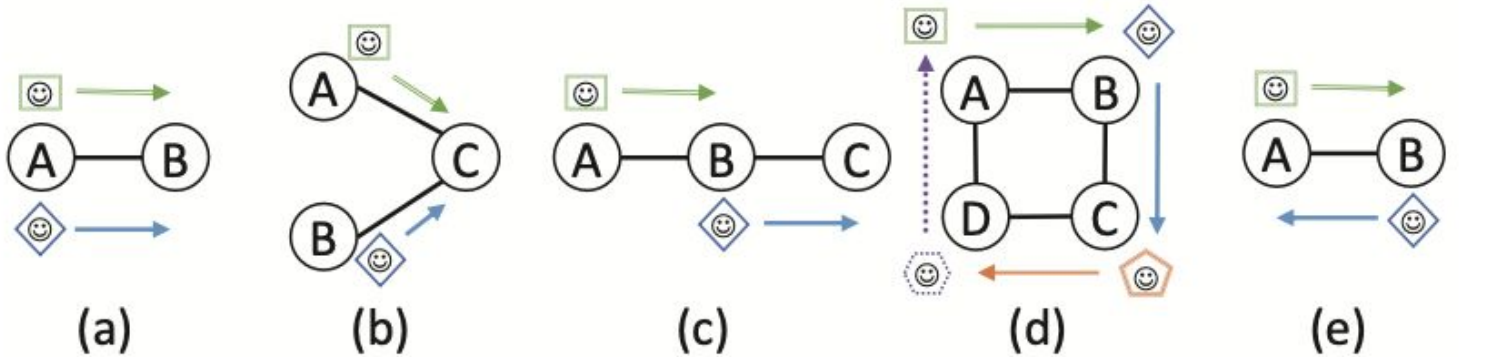


Image source: (Stern et al., *Multi-agent pathfinding: Definitions, variants, and benchmarks* 2021)

Objective functions

- Makespan
- Total Completion time
- Path length

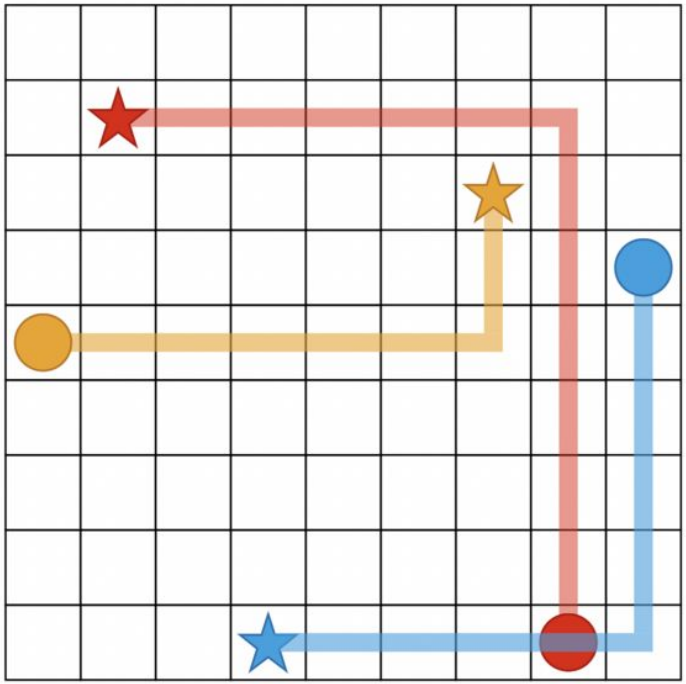


Image source:
https://upload.wikimedia.org/wikipedia/commons/c/c3/Example_of_Multi-Agent_Path_Finding_in_a_grid_environment.png

Extensions

- Heterogeneous MAPF
  - Different behaviour
  - Different capabilities
- Lifelong MAPF

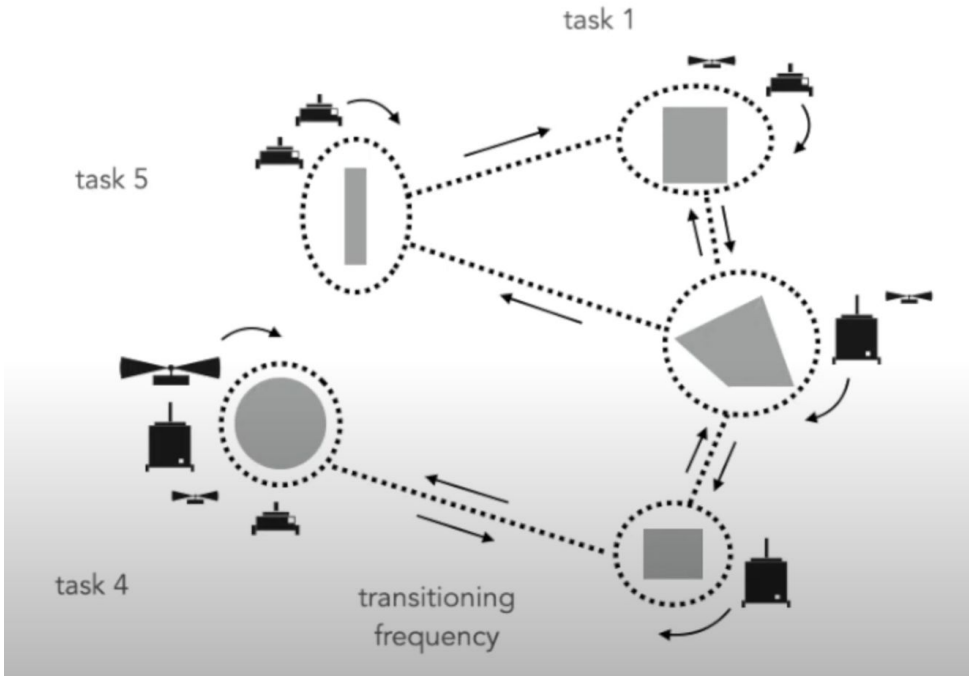


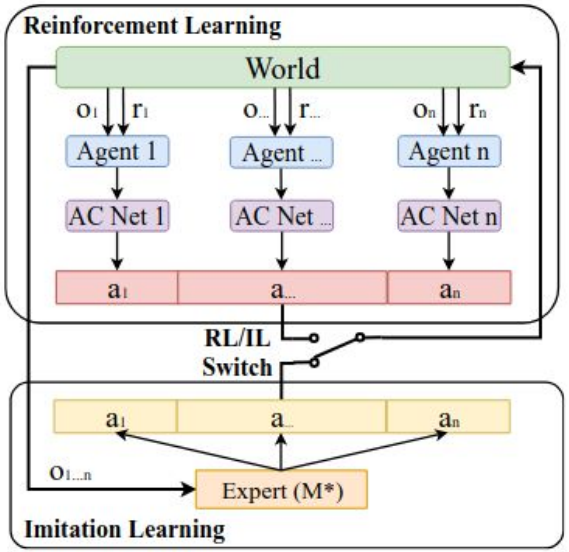
Image source: https://www.youtube.com/watch?v=pWPZfmqcJA4&t=3199s

Learning-based approach

- Reasons to use a learning-based approach:
  - Scalable
  - Online decision making
  - Works with imperfect information
- Reinforcement learning
  - Selfish agents

PRIMAL: Pathfinding via Reinforcement and Imitation Multi-Agent Learning

- Problem
  - Selfish agent
- Solution
  - Blocking penalty
  - Combining RL and IL
  - Environment sampling

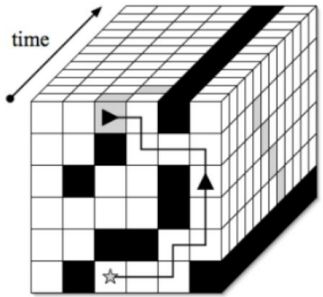


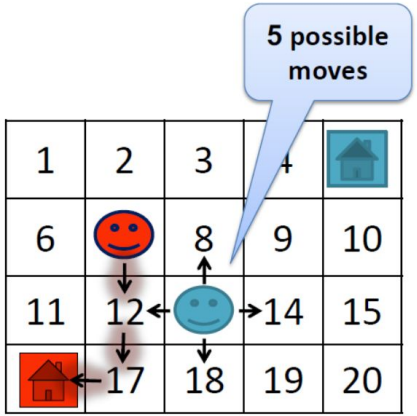
[1] Guillaume Sartoretti , Justin Kerr , Yunfei Shi, Glenn Wagner, T. K. Satish Kumar, Sven Koenig, and Howie Choset. “PRIMAL: Pathfinding via Reinforcement and Imitation Multi-Agent Learning”. IEEE (2019)

Search-based approach

- Construct a graph with a time dimension
- Map set of states to single vertex
- Cooperative search algorithms

Prioritized Planning (Silver 2005) Analysis: Second Agent

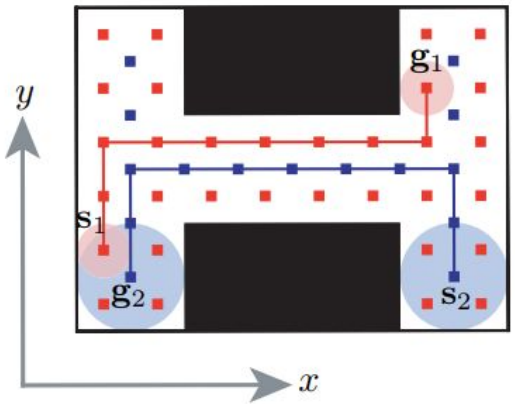




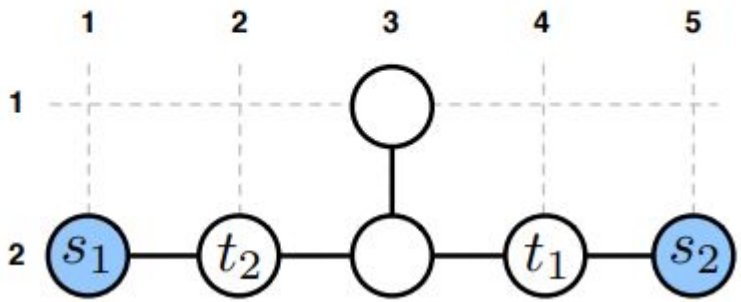
- A state is a (location,time) pair
- Number of states = 4 x 5 x maxTime
- Branching factor = 4+1

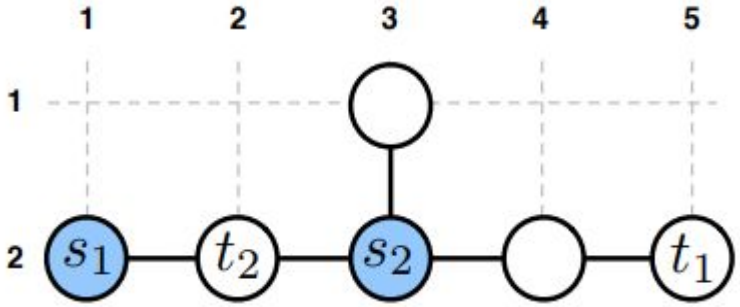
Priority-based search

- Decompose into multiple single agent pathfinding problems
- Use fixed priority and work around more important agents
- Heuristics to determine order



Priority-based approach





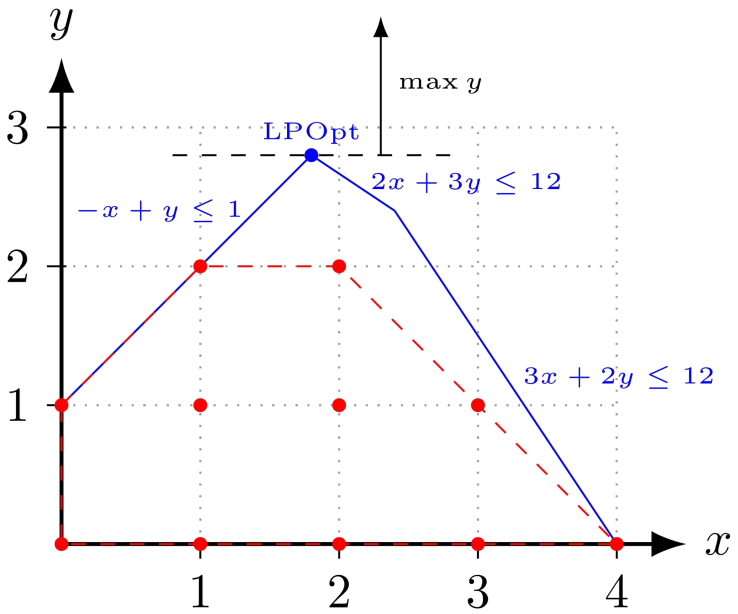
Consistent Prioritization for MAPF

- Explores all partial priority orderings
- Lazily adds partial orderings when collision is encountered
- Backtracks to find optimal ordering

[2] Hang Ma, Daniel Harabor, Peter J. Stuckey, Jiaoyang Li, Sven Koenig. “Searching with Consistent Prioritization for Multi-Agent Path Finding”. AAAI (2019)

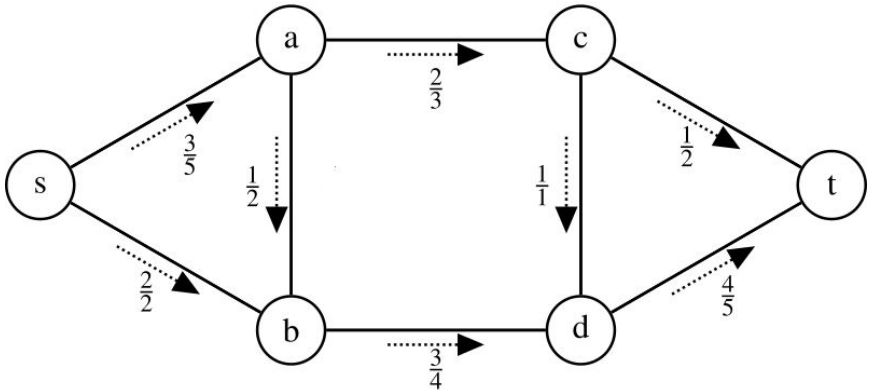
Optimization-based approach

- Convert to integer program
- Use standard IP solver



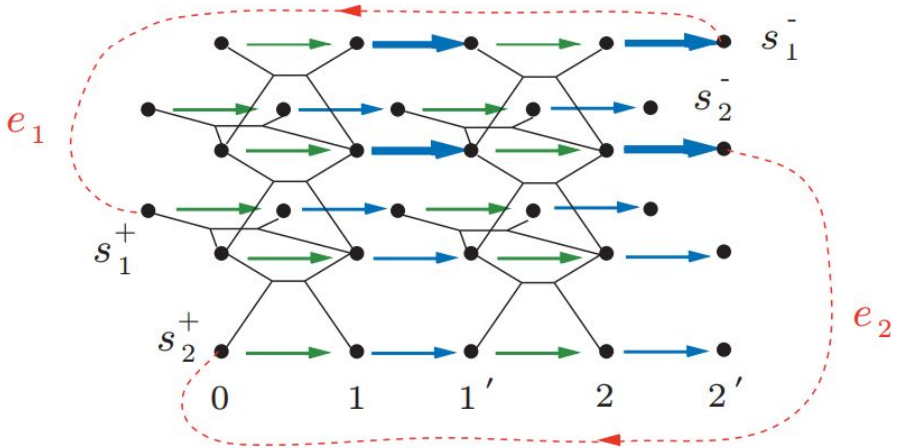
How to create an integer program?

- Direct mapping of space-time graph
- Multi-commodity network flow



Optimal Multi-Robot Path Planning on Graphs: Complete Algorithms and Effective Heuristics

- Found efficient algorithms for four objectives
- Even more speed-up with heuristics



[3] Yu, Jingjin and LaValle, Steven M. “Optimal Multi-Robot Path Planning on Graphs: Complete Algorithms and Effective Heuristics”. IEEE (2016)

Thank you for listening

Quiz

Choose the statement that matches with cycle conflict

a) Two agents try to move along the same edge at the same time
b) A group of agents end up wanting to move in a loop, each into the next position at the same time.
c) Two agents plan to swap positions by crossing each other's paths in one move, leading to a collision.

What is the main drawback of priority-based search

a) Computation time
b) Lack of completeness
c) No guarantee of collision avoidance
d) Lack of optimality