# Online Multi-Agent Pathfinding

## Intelligent Robotics

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Technical Aspects of Multimodal Systems

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# Gliederung (Agenda)

# What is Pathfinding?

## Definition

Pathfinding is the ability for an artificial intelligence system to deduce the proper path around obstacles to reach a destination point. [6]

# Games


Figure: Pathfinding: Age of Empires [10]

# Navigation

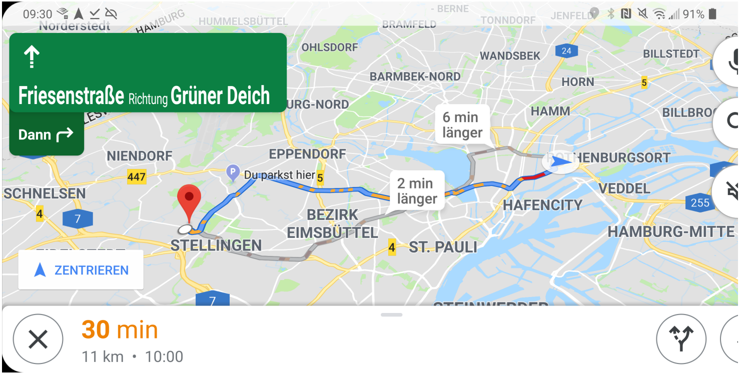


Figure: Pathfinding: Navigation

# Robotics

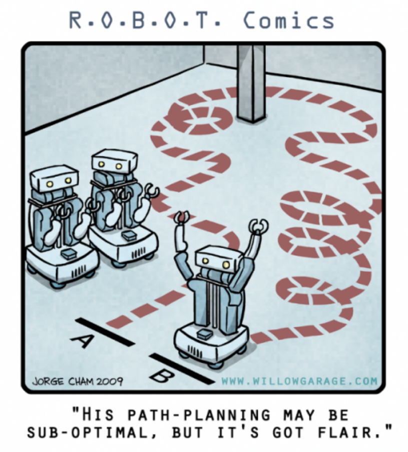


Figure: Pathfinding: Robotics [2]

# Algorithms

- Depth First Search
- Breadth First Search
- Dijkstra
- A*
- Hierachical path finding
- ...

# Differences

- Multiple agents
- Planning of:
  - Multiple Paths
  - Free of collisions with other agents

# Problem

- $A$ is set of $k$ agents

$$\langle G, s, g\rangle \text{ where } G = (V, E) \text{ is an undirected Graph}$$
$$s : [1, ..., k] \to V \text{ source positions}$$
$$g : [1, ..., k] \to V \text{ target positions}$$

- Agent $i \in A$ takes an action $a : V \to V$ such that $a(v) = v'$ either *wait* or *move*
- Sequence of actions:

$$\pi_i[x] = a_x(a_{x-1}(\cdots a_1(s(i))))$$

- Goal:

$$\forall i \in A \exists \pi_i[x] : \pi_i[x] = g(i)$$

# Agent Behavior at Target

- Stay at target
- Disappear at target

# Objective Functions

- Makespan:
  - Maximum time for all agents to reach their target
- Sum of costs:
  - Sum of time steps by each agent
  - Stay at target needs definition
- ...

# Conflicts

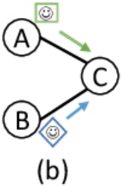


Figure: Vertex Conflict [8]

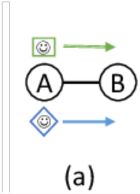


Figure: Edge Conflict [8]

# Conflicts (cont.)

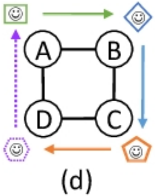


Figure: Circle Conflict [8]

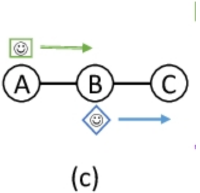


Figure: Following Conflict [8]

# Conflicts (cont.)

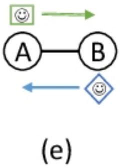


Figure: Swap Conflict [8]

# Current Research

- MAPF with large Agents [4]
- MAPF with kinematic constraints [1]
- Non discrete time $\rightarrow$ weighted graph
- Anonymous MAPF [3]
- Colored MAPF [5]
- **Online MAPF** [9]

# The Paper

- Title: Online Multi-Agent Pathfinding
- Author: Jiří Švancara from Charles University, Prague
- Published: 2019-07-17
- Location: AAAI 2019 - Honolulu, Hawaii

# Definition

- Bring in a little twist:
  - Add a new set of triplets $\langle t_i, s_i, g_i \rangle$
  - $t_i$ timestep in which agent $i$ appears
- Awarness of new agent $i$ only iff $t = t_i \rightarrow$ **online**
- New solutions every time new agent appears

# Entering and Leaving

- New agent appears
  - Problems can occur
  - Vertex can be occupied in that timestep
  - Where was the agent before?
- Agent reaches goal
  - Stay at target
  - Leave environment
- Some kind of outer world is needed

# Objective Functions

- Makespan
  - Online MAPF has no end
  - Makespan metric tends to $\infty$
- Sum of cost
  - Works well if agents leave the environment or *wait* is ignored

# Optimal Solution

- Two agents, one wants to go 1 $\rightarrow$ 4 the other 3 $\rightarrow$ 1
- Second agent arrives at $t = 1$

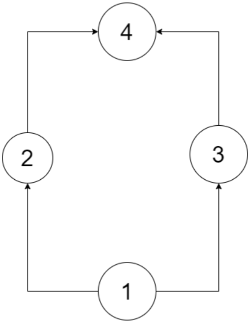


Figure: Optimal Solution

$\rightarrow$ There is no completely optimal online MAPF Solver

# Snapshot Optimality

**Definition**

A snapshot optimal plan in an online MAPF setting is a plan for all agents to their goal that is optimal in terms of sum of costs assuming no new agent will appear in the future. [9]

- Simulation results approve this [9]
- Not optimal but tends to an overall low sum of cost

# Replan Single / Grouped

- **Replan Single**
  - Search for optimal plan for each **new** agent in serial
  - Able to use SAPF algorithms
  - Solvable in polynomial time

→ Not snapshot optimal

- **Replan Single Grouped**
  - Search for optimal plan for each **new** agent in parallel

→ Not snapshot optimal

# Replan All

- **Replan All**
  - Search for optimal plan for each agent in parallel
  - Not scalable in any way

$\rightarrow$ Snapshot optimal iff MAPF algorithm is optimal

# Online Independence Detection

- Based on the Independence Detection Algorithm [7]
- “Agent do not interfere with each other”

1. Every agent is a group of size 1
2. Plan for each group
3. Conflict $\rightarrow$ merge groups of conflicting groups
4. Goto 2

# Online Independence Detection (cont.)

- Problem with groupings in past timesteps
- Optimal paths based on conflicts can change
- Save groupings of the last timestep

# Main Applications

- Autonomous driving in set environments (e.g. Hamburg City-Center)
- Intersection managment
- Navigation
- Warehouse worker

# Warehouse Video

Show Video and Video

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[2] Jorge Cham. *R.O.B.O.T. Comics: Path Planning*. [Online; accessed November 19, 2019]. 2009. URL: http://www.willowgarage.com/blog/2009/09/04/robot-comics-path-planning.

[3] S. Kloder and S. Hutchinson. "Path Planning for Permutation-Invariant Multi-Robot Formations". In: *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*. 2005, pp. 1797–1802. DOI: 10.1109/ROBOT.2005.1570374.

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[9] Jirí Svancara, Marek Vlk, Roni Stern, Dor Atzmon, and Roman Barták. "Online Multi-Agent Pathfinding". In: *AAAI*. 2019.

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