Making Solutions of Multi-robot Path Planning Problems Shorter Using Weak Transpositions and Critical Path Parallelism

Pavel Surynek
Department of Theoretical Computer Science and Mathematical Logic
Faculty of Mathematics and Physics, Charles University in Prague, The Czech Republic

Problem of Multi-robot Path Planning

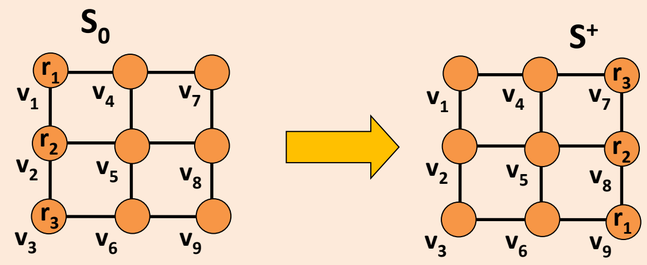
Input: Graph **G=(V,E)** and a set of robots **R={r_1,r_2,…,r_μ}**, where **μ<|V|**

- **each robot** is placed **in a vertex**
- at most **one** robot in a vertex
- a **robot can move into** a neighboring vertex
- the **target vertex** must be free or being left (no other robot is allowed to enter the same target vertex)

- **initial positions** of robots … simple function **S_0: R→V**
- **goal positions** of robots … simple function **S^+: R→V**

Output: A sequence of valid moves for robots such that all the robots reach their goal positions starting from the given initial positions

Example of Multi-robot Path Planning



Solution length=6

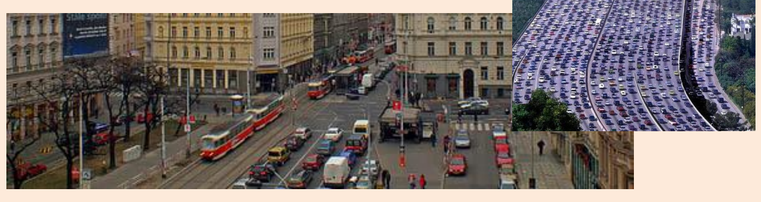
P_{r1}=[**v_1**, v_4, v_7, v_8, **v_9**]
P_{r2}=[**v_2**, v_1, v_4, v_7, **v_8**]
P_{r3}=[**v_3**, v_6, v_1, v_4, **v_7**]

Step: **1 2 3 4 5**

- a **sequence of vertices** representing valid moves is assigned to each robot
- a **solution** consists of such sequences for each robot

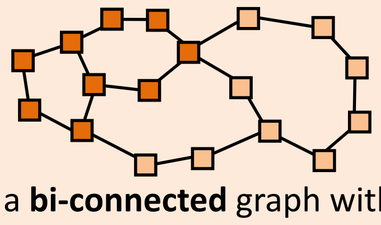
Motivation for the Problem

- **rearranging** containers (robot = container)
- heavy traffic **control** (robot = car)
- **data transfer** planning (robot = data packet)



Solving Methods to Improve

- improvement of **existing algorithms**
- there exist several solving algorithms for **bi-connected** graphs (≥ 1 free)
- optimal sub-solutions (**macros**) for **θ-like** sub-graphs are used to compose a solution



a **bi-connected** graph with (**θ-like** sub-graph highlighted)

Weak Transposition Macros in θ-like Graphs

- use **weak transposition macros** instead of standard transposition macros
- weak transposition macro **doesn't care** about a subset of robots (in **red vertices**)
- **weaker constraint** → solution composed of weak transposition macros is **shorter**

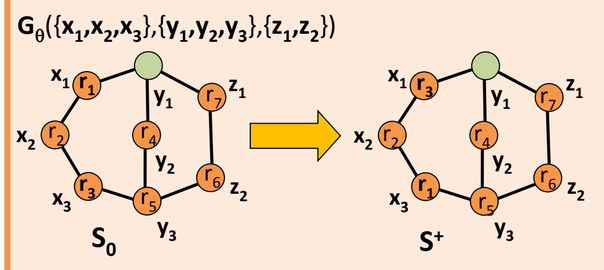


Illustration of **standard transposition** macro of r_1 and r_3 in **θ-like graph**

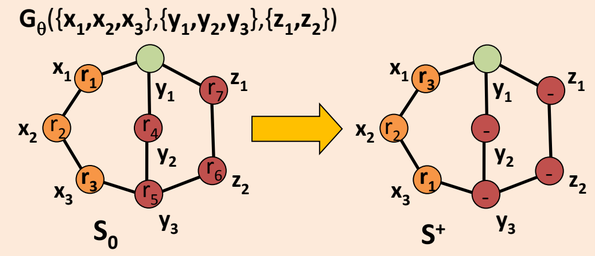
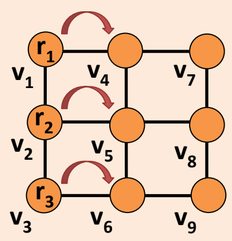
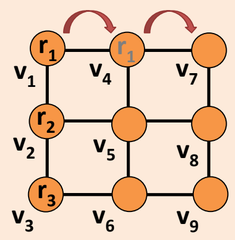


Illustration of **weak transposition** macro of r_1 and r_3 in **θ-like graph**

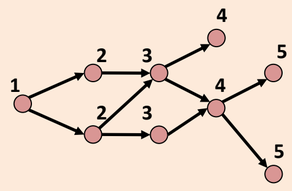
Critical Path Parallelism



Independent moves can be performed in **parallel**



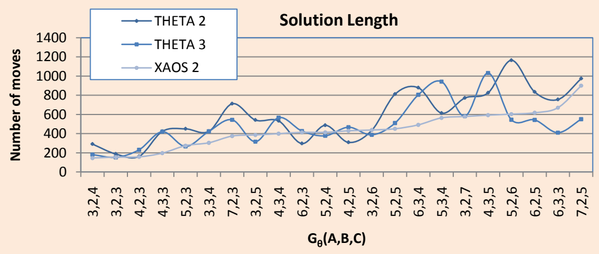
Dependent moves must be performed **sequentially**

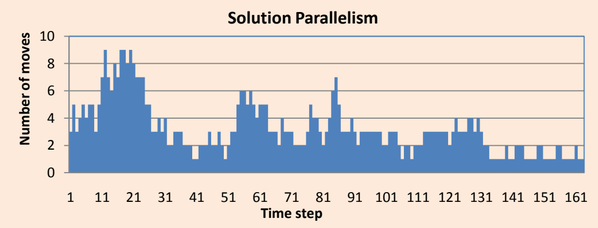


- define DAG=**(V,E)**
- **V** = moves
- **E** = dependent moves

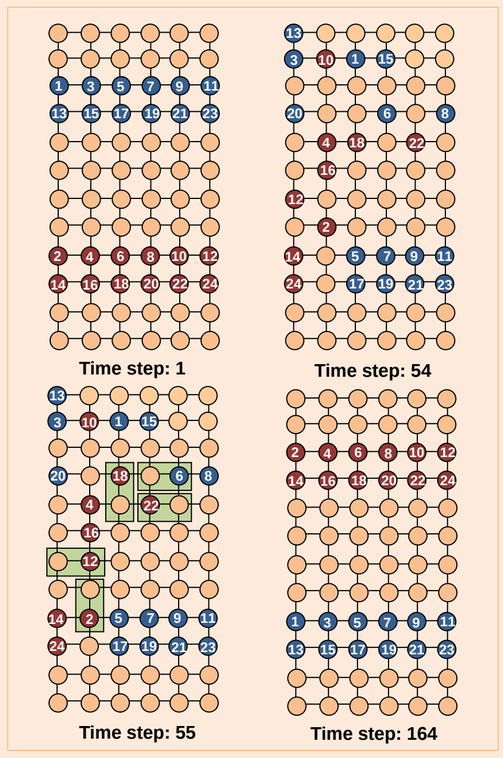
- calculate **earliest execution time** for each move **- critical path**

Experimental Evaluation





- **weak transpositions** lead to solution shortening
- **critical path parallelism** shorten solutions yet more



References

Pavel Surynek: ***"A Novel Approach to Path Planning for Multiple Robots in Bi-connected Graphs"***, Proceedings of the 2009 IEEE International Conference on Robotics and Automation (**ICRA 2009**), pp. 3613-3619, IEEE Press, 2009.

Pavel Surynek: ***"Towards Shorter Solutions for Problems of Path Planning for Multiple Robots in θ-like Environments"***, *Proceedings of the 22nd International FLAIRS Conference* (**FLAIRS 2009**), pp. 207-212, AAAI Press, 2009.

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