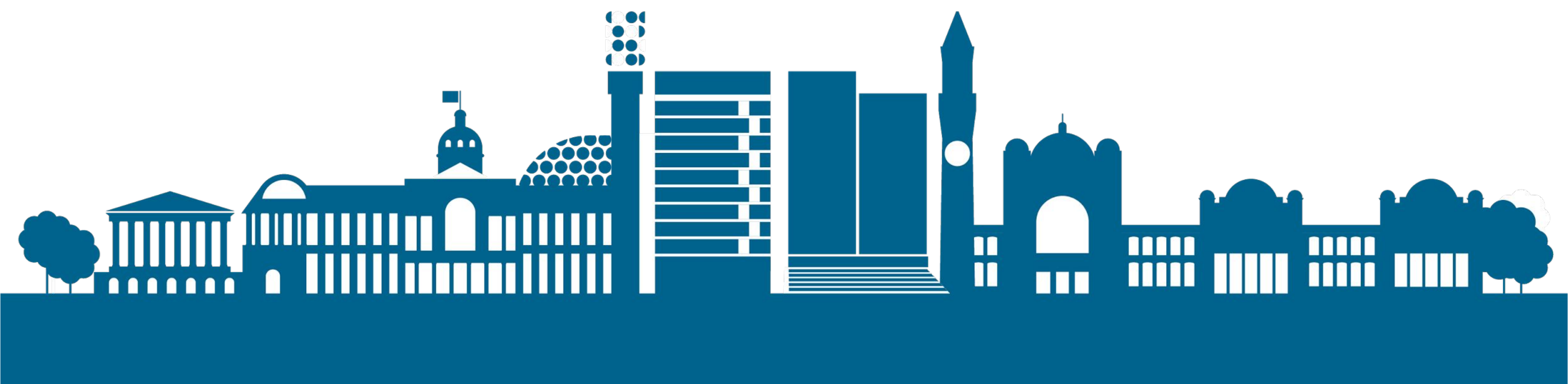
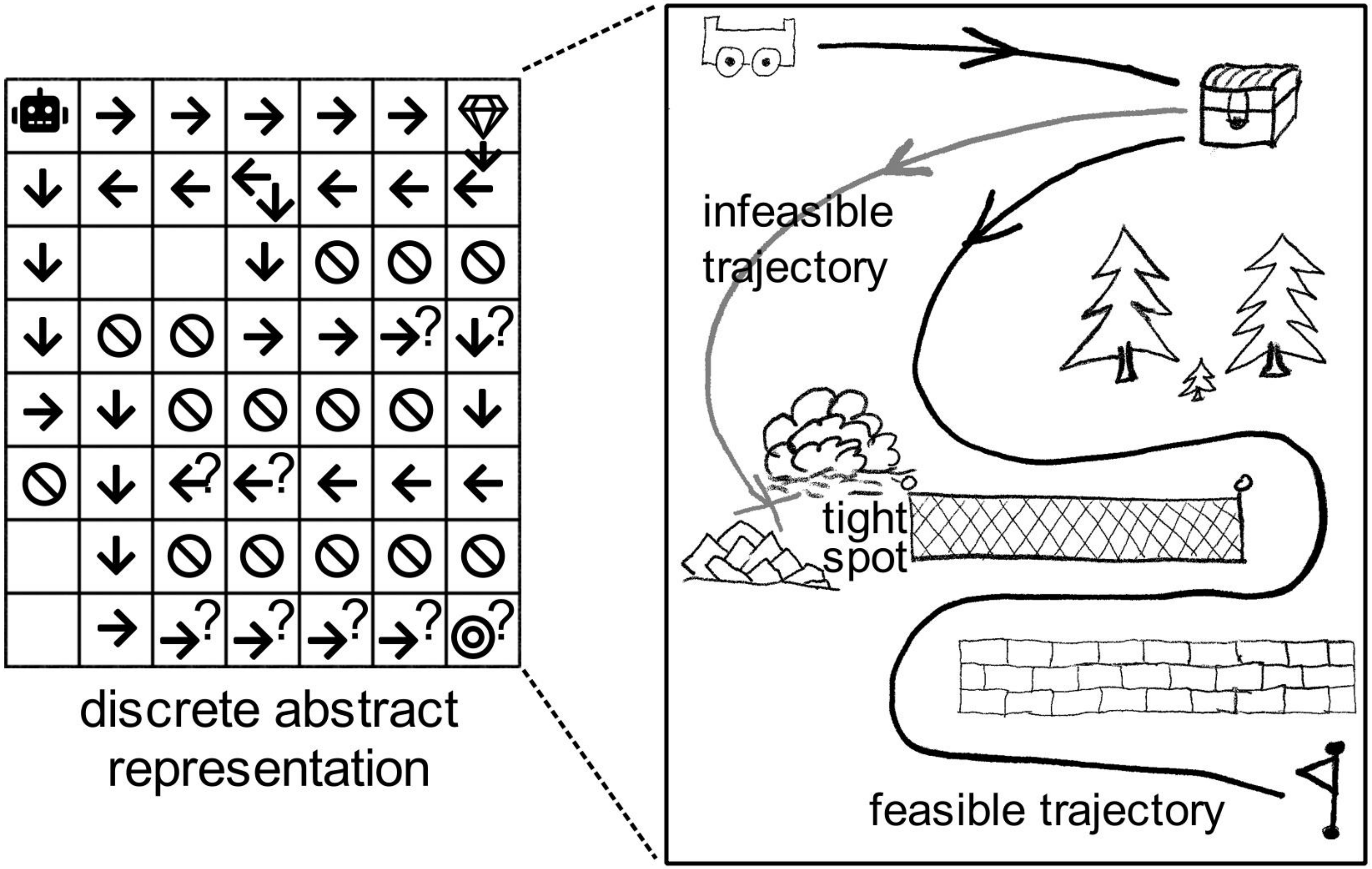
UNIVERSITY OF BIRMINGHAM

# Combining Task and Motion Planning: Challenges and Guidelines

Masoumeh Iran Mansouri, School of Computer Science



# What is TAMP?

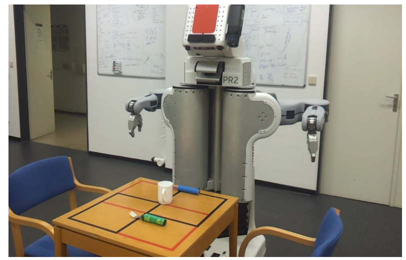


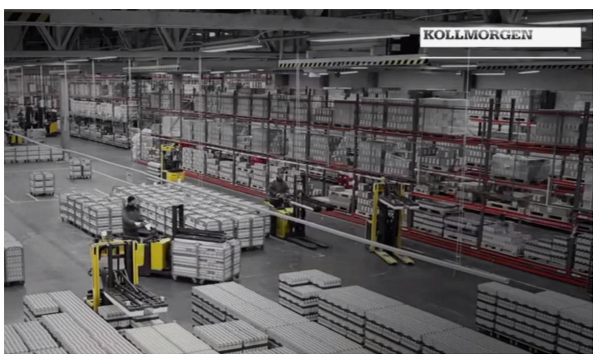

discrete abstract representation

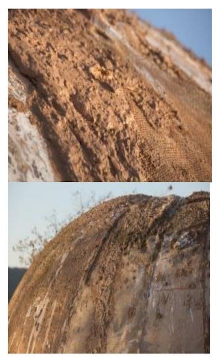
continuous motion representation

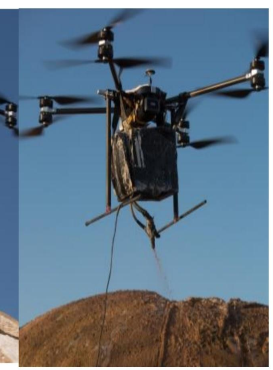
# What is TAMP?


Primary Crusher
Wheel Loader
Secondary Crusher


PR2


KOLLMORGEN





# What is TAMP?

Mining robots drilling


Construction

Assembling of wiper motors

# Research questions

**Q1: (Abstraction)** How can a domain be divided into multiple levels of abstraction, and what are effective methods for finding a globally feasible solution that obeys all constraints in all abstraction levels?

**Q2: (Symbolic Versus Continuous Models)** How should symbolic and continuous knowledge representations be reasoned upon jointly?

# Research questions

**Q3: (Specifying Versus Learning)** What classes of methods exist for learning models, specifying models, and performing the two together? In particular what are the options for combining existing task and motion planning methods with machine learning?

**Q4: (Online Planning)** How to enable online decision making in combined task an motion planning? How can we guarantee the consistency of decision-making in such settings?

# Research questions

**Q5: (Planning With Uncertainty)** Which methods should be used to deal with uncertain perception in combined task and motion planning? Should uncertainty be considered in one of the decision making processes or both?

frontiers
in Robotics and AI | Robotic Control Systems



**REVIEW article**

Front. Robot. AI, 19 May 2021 | https://doi.org/10.3389/frobt.2021.637888

# Combining Task and Motion Planning: Challenges and Guidelines

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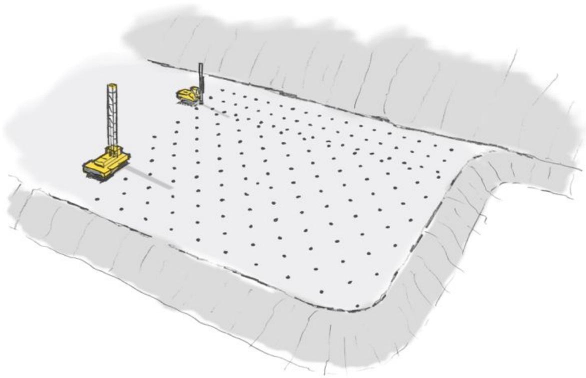
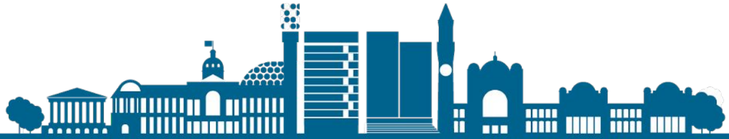
[3]Knowledge-Based Systems Group, TU Wien, Vienna, Austria

# The Drill Planning for open-pit mines

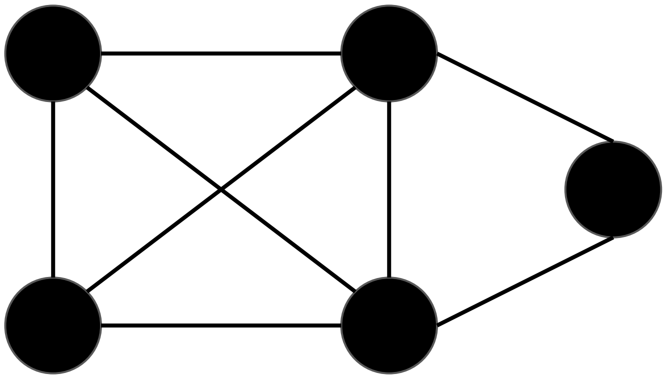

Courtesy of Epiroc



**Problem:** Plan motions and drilling sequences for multiple machines such that the makespan minimized.



# It is like a Traveling Salesperson Problem (TSP) But ...



Edges become "disabled" dynamically based on current path selection

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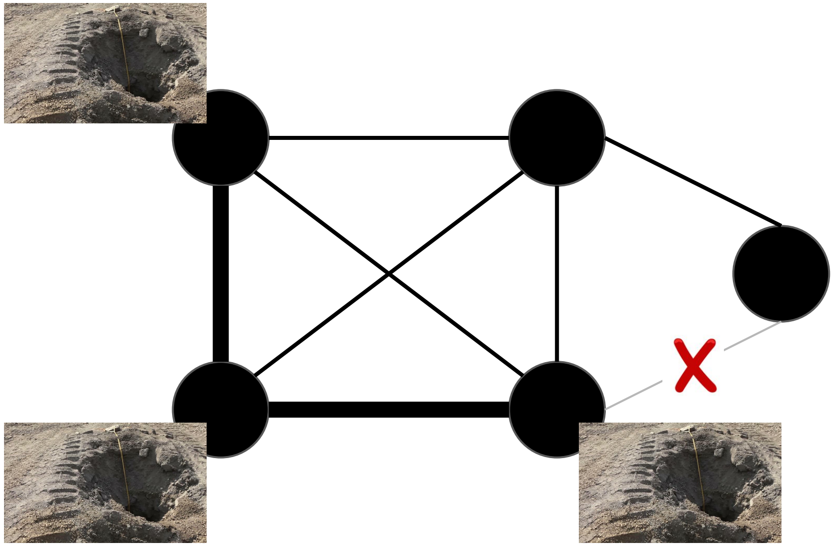


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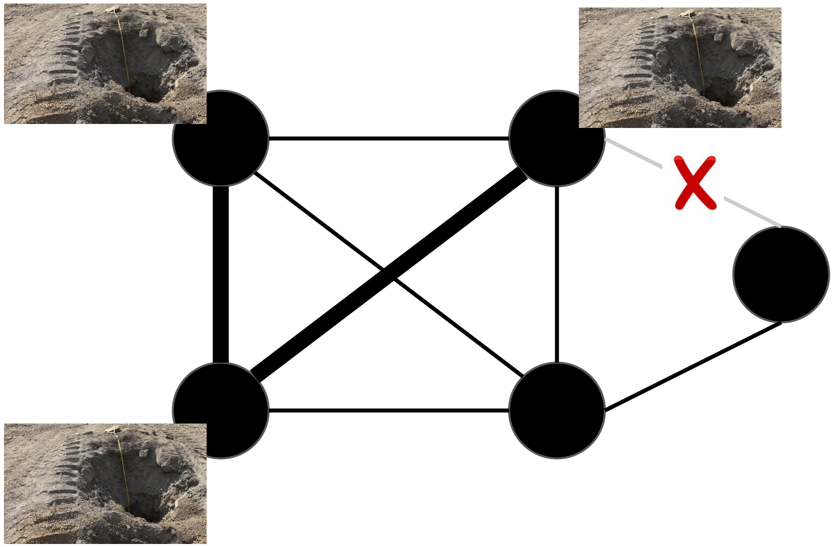
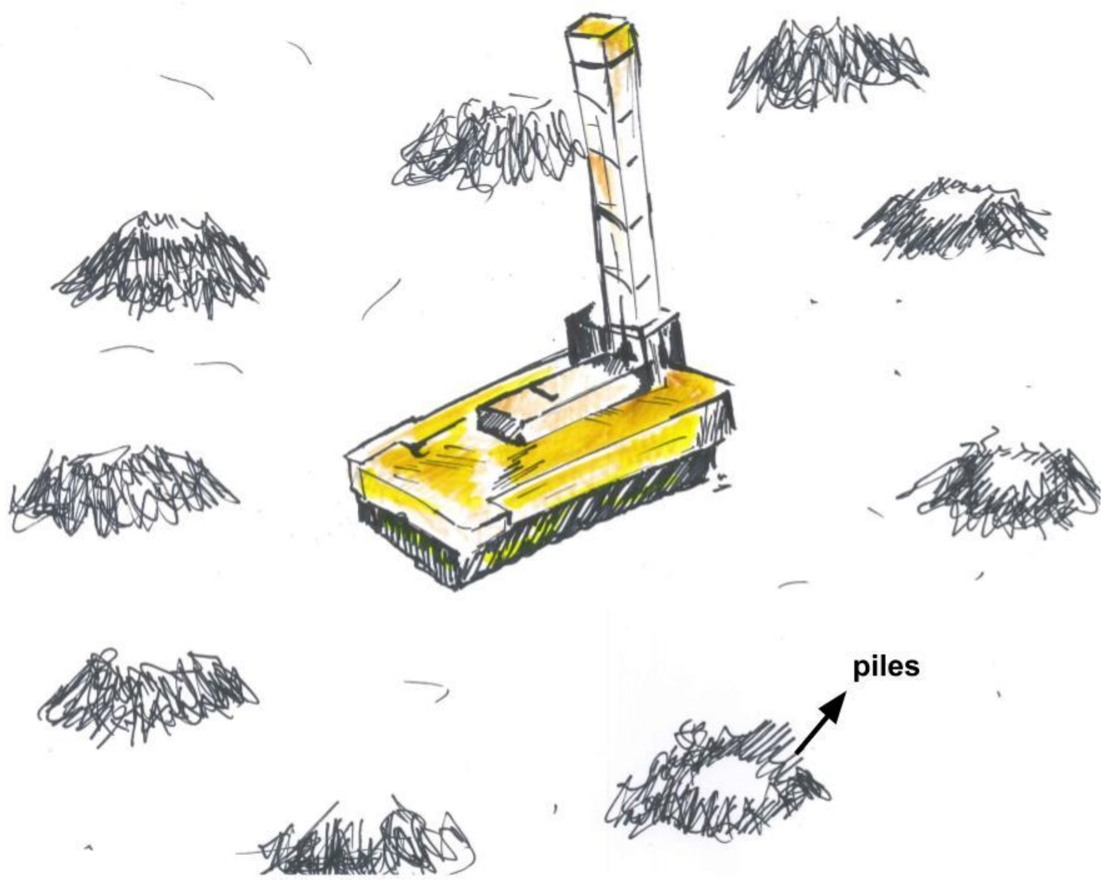



Edges become "disabled" dynamically based on current path selection

# Not Addressing Interdependency Leads to a Deadlock



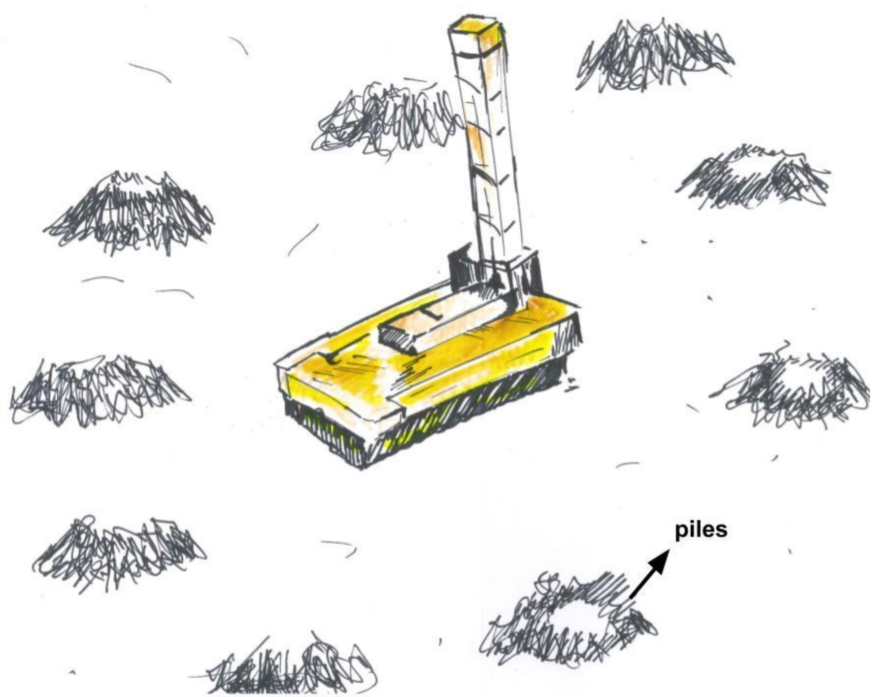
# Drill Plan requirements

[M. Mansouri, et al., Multi Vehicle Routing Problem with Nonholonomic Constraints and Dense Dynamic Obstacles, IROS 2017]

- Uncertain navigation duration

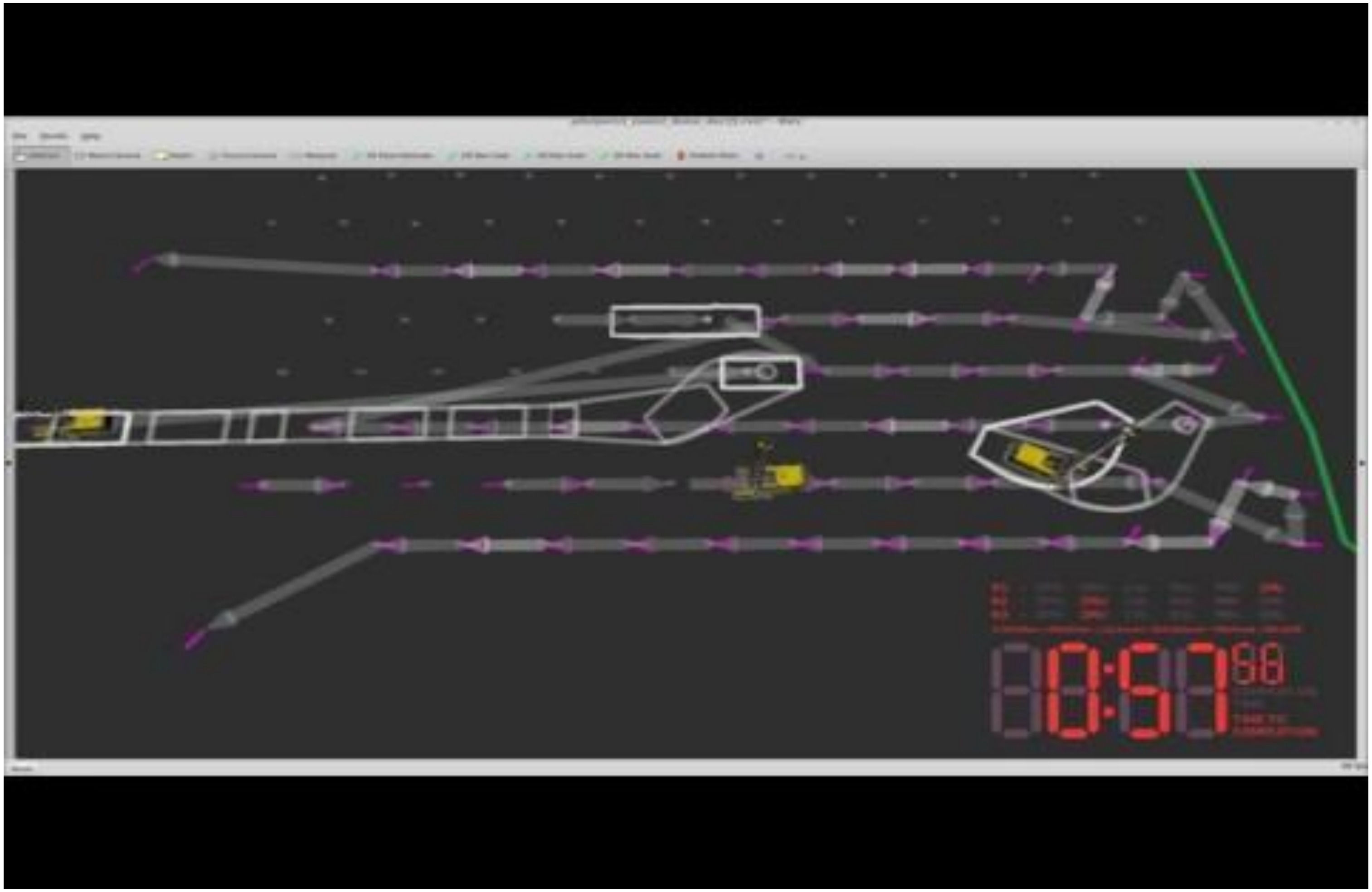
The solution should consider:

- hardness of the rock
- Machine breakdown
- Robot-robot collision
- ....



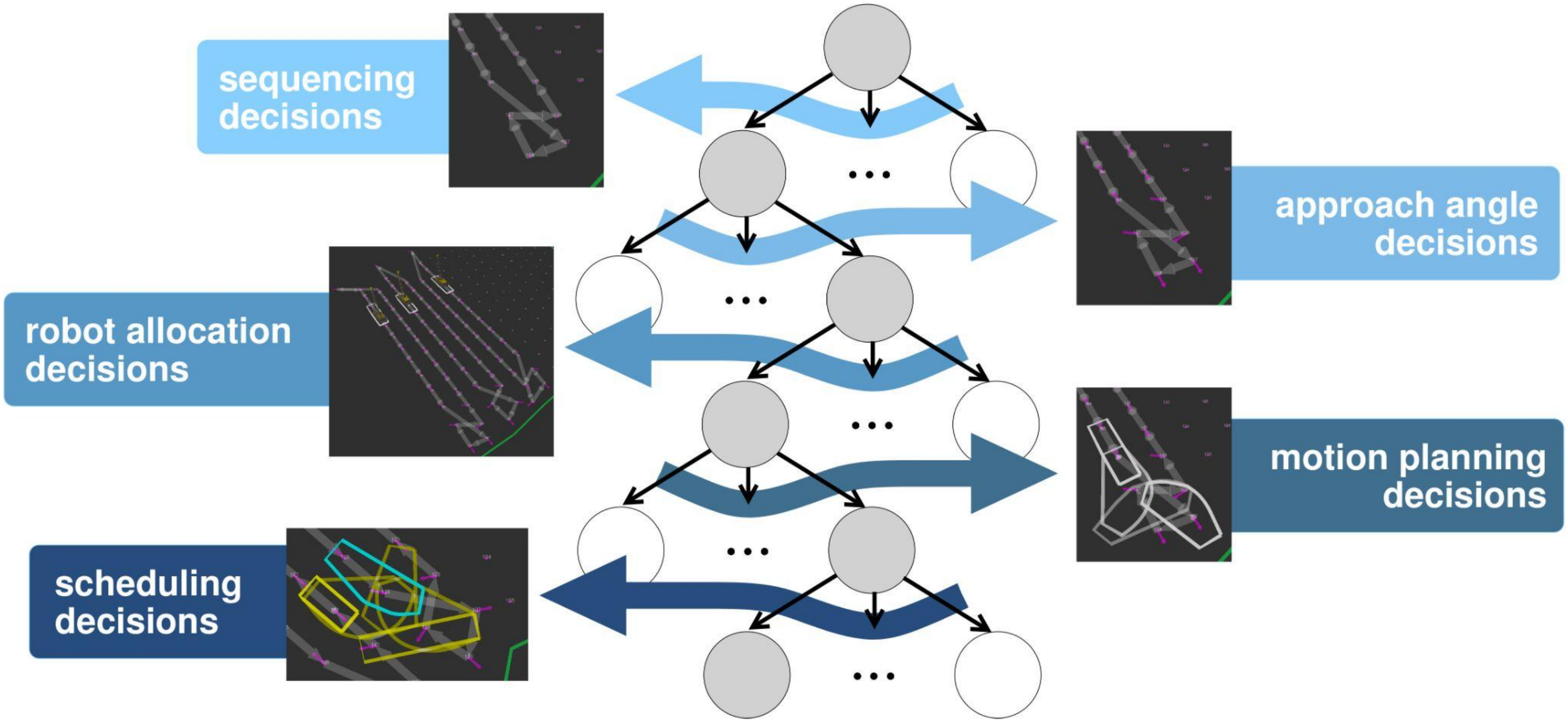
# The Drill Planning for open-pit mines

[M. Mansouri, et al., Hybrid Reasoning for Multi-robot Drill Planning in Open-pit Mines, IROS 2015]



# Solution 1: Meta-CSP

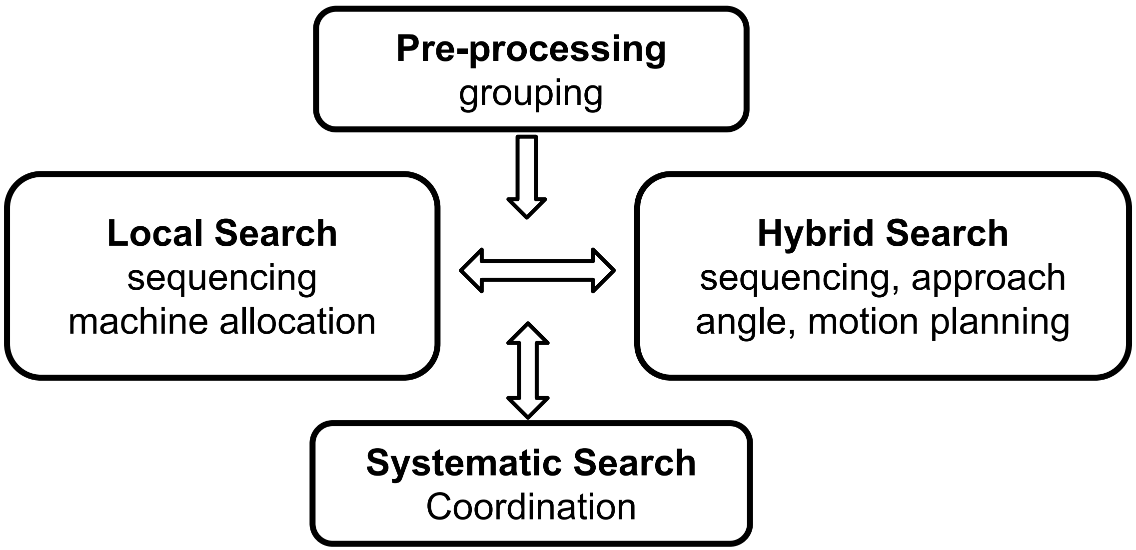
[M. Mansouri, et al., Hybrid Reasoning for Multi-robot Drill Planning in Open-pit Mines, IROS 2015]

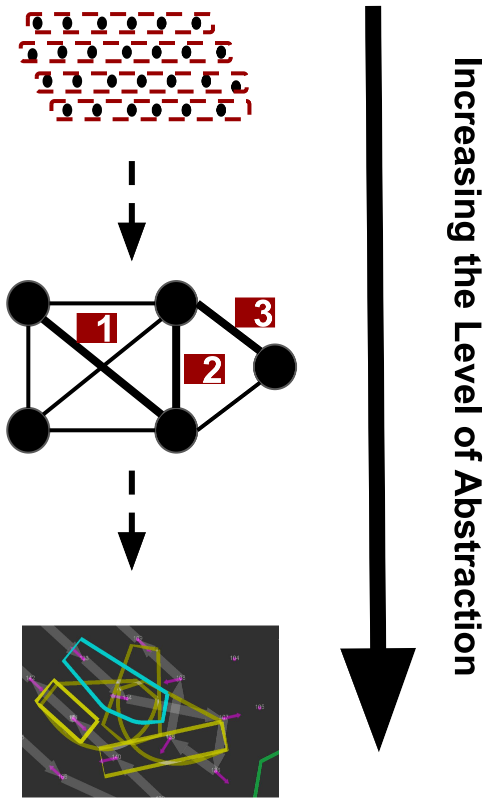



**Search in the Space of Sub-Problems: Assignments to decision variables explored via backtracking**

# Solution 2: Multi-abstraction Search

[M. Mansouri, et al., Multi Vehicle Routing Problem with Nonholonomic Constraints and Dense Dynamic Obstacles, IROS 2017]



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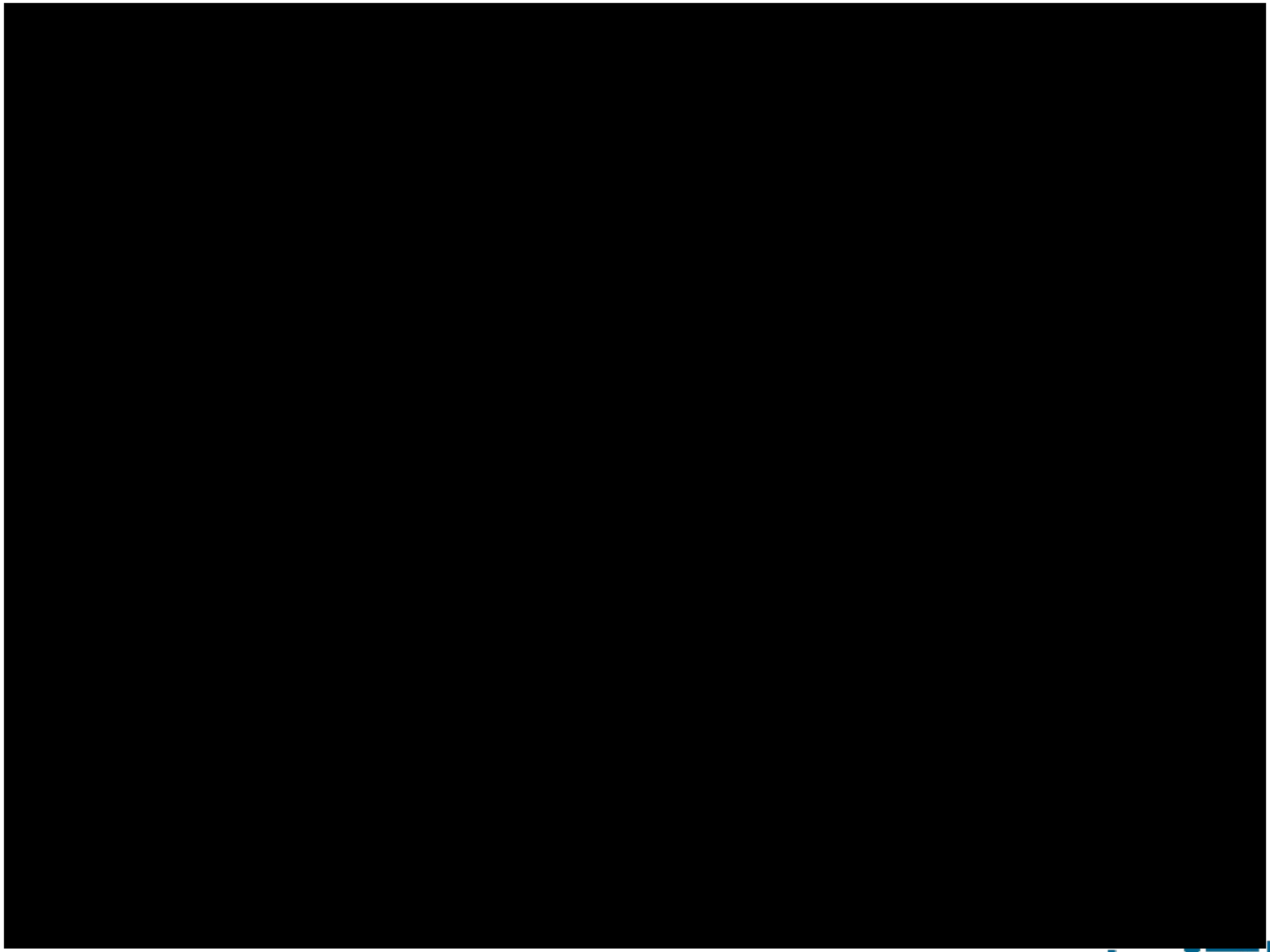
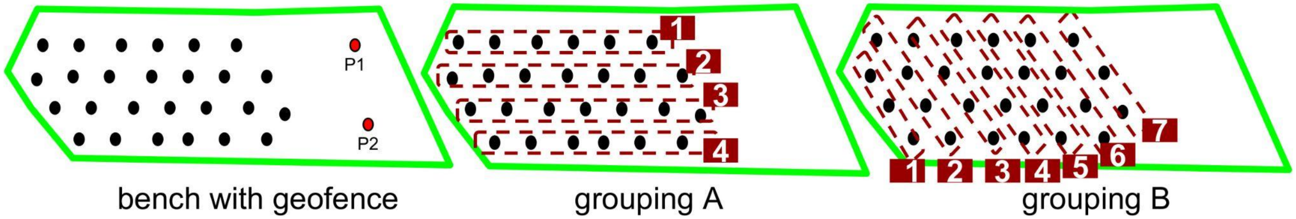


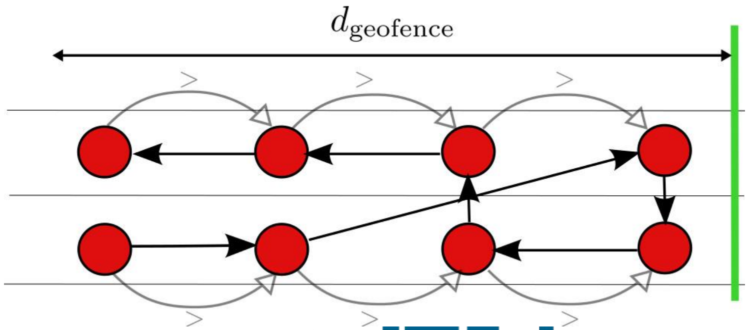
# Considerations

- Q1: (Abstraction)
- Q2: (Symbolic Versus Continuous Models)
- Q3: (Specifying Versus Learning)

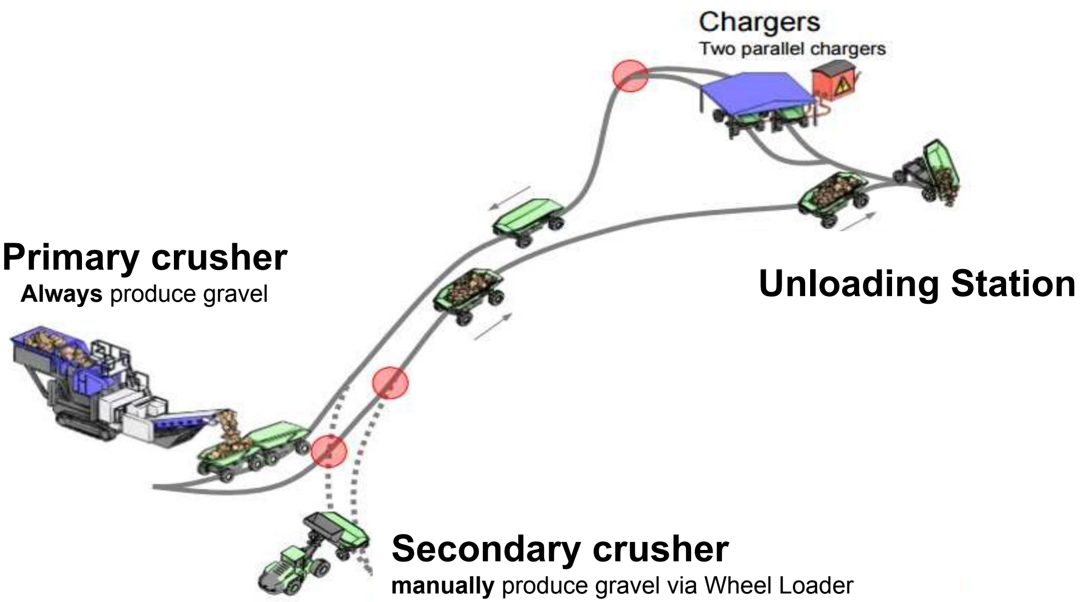
**Clustering**

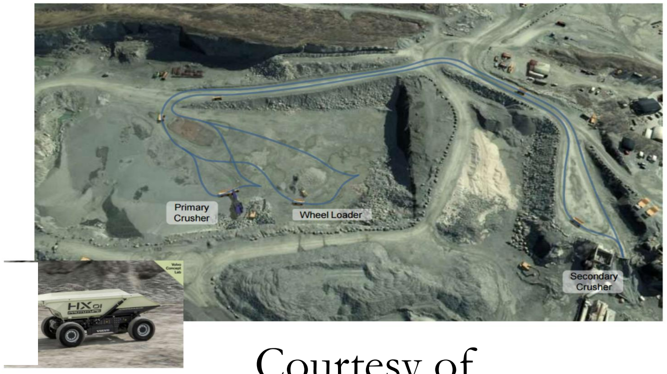



**Learning Heuristics**



# Multi-hauler planning for quarrying




Courtesy of Volvo CE

**Problem:** Multi-Robot Planning Under Uncertain Travel Times and Safety Constraints

# Multi-hauler planning for quarrying

[M. Mansouri, B. Lacerda, N. Hawes, F. Pecora, Multi-Robot Planning Under Uncertain Travel Times and Safety Constraints, IJCAI 2019]

- Robot dynamics are **partially** known
- Robots may **navigate differently** in different parts of the environment
- There may be **task-dependent** factors affecting **how** robots navigate

# Multi-hauler planning for quarrying

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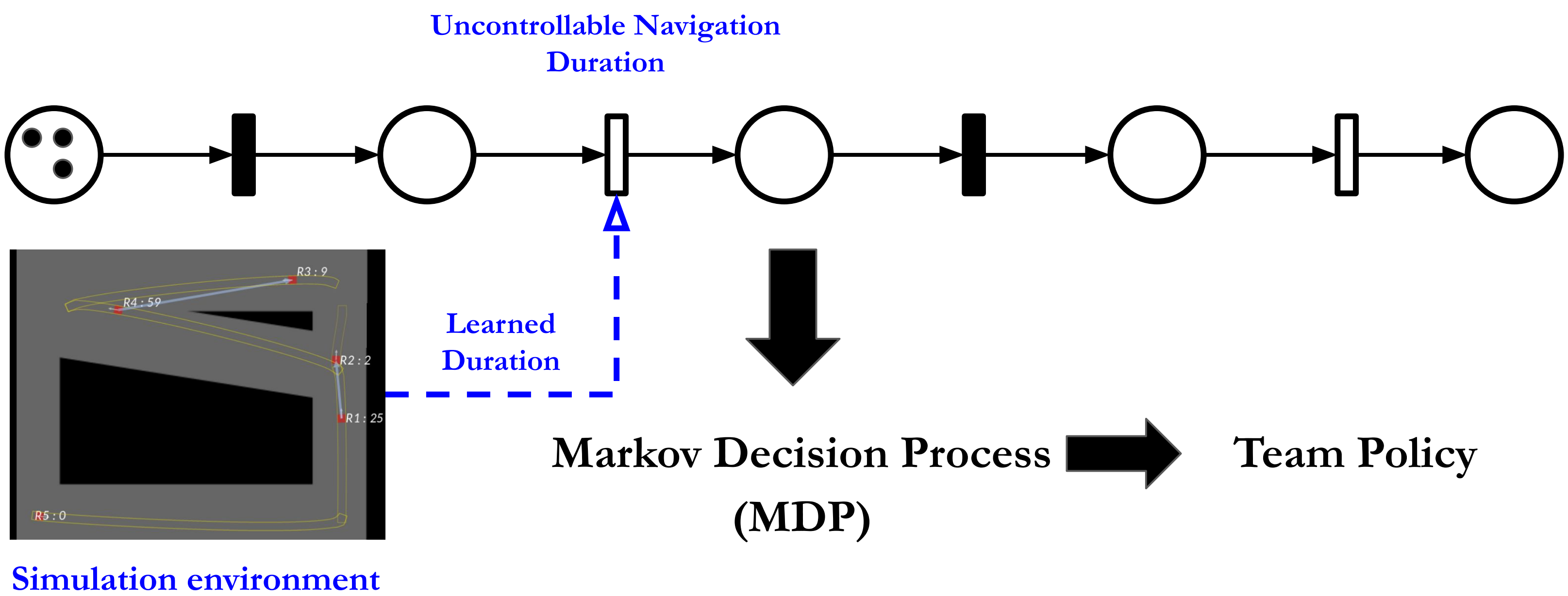

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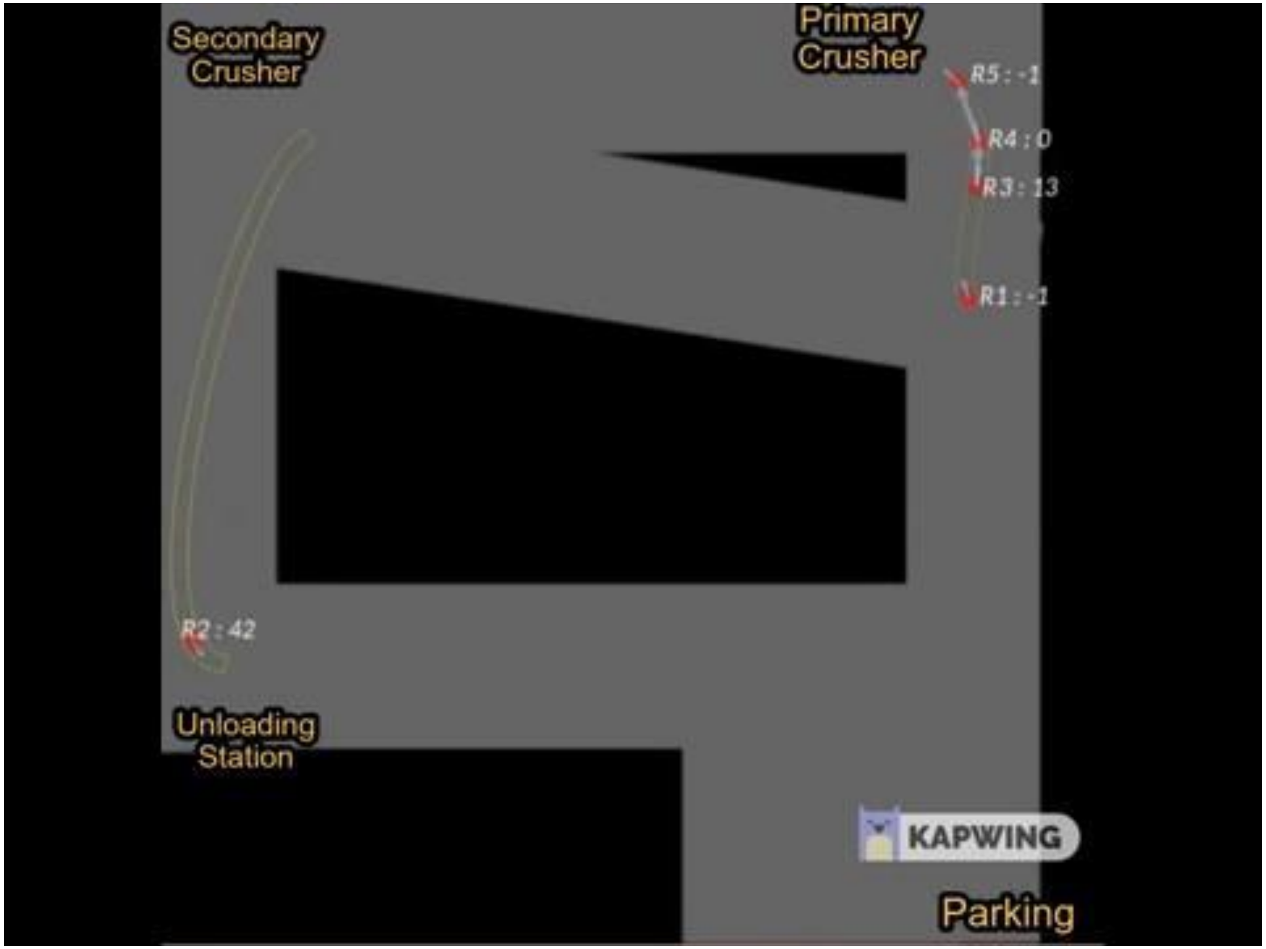
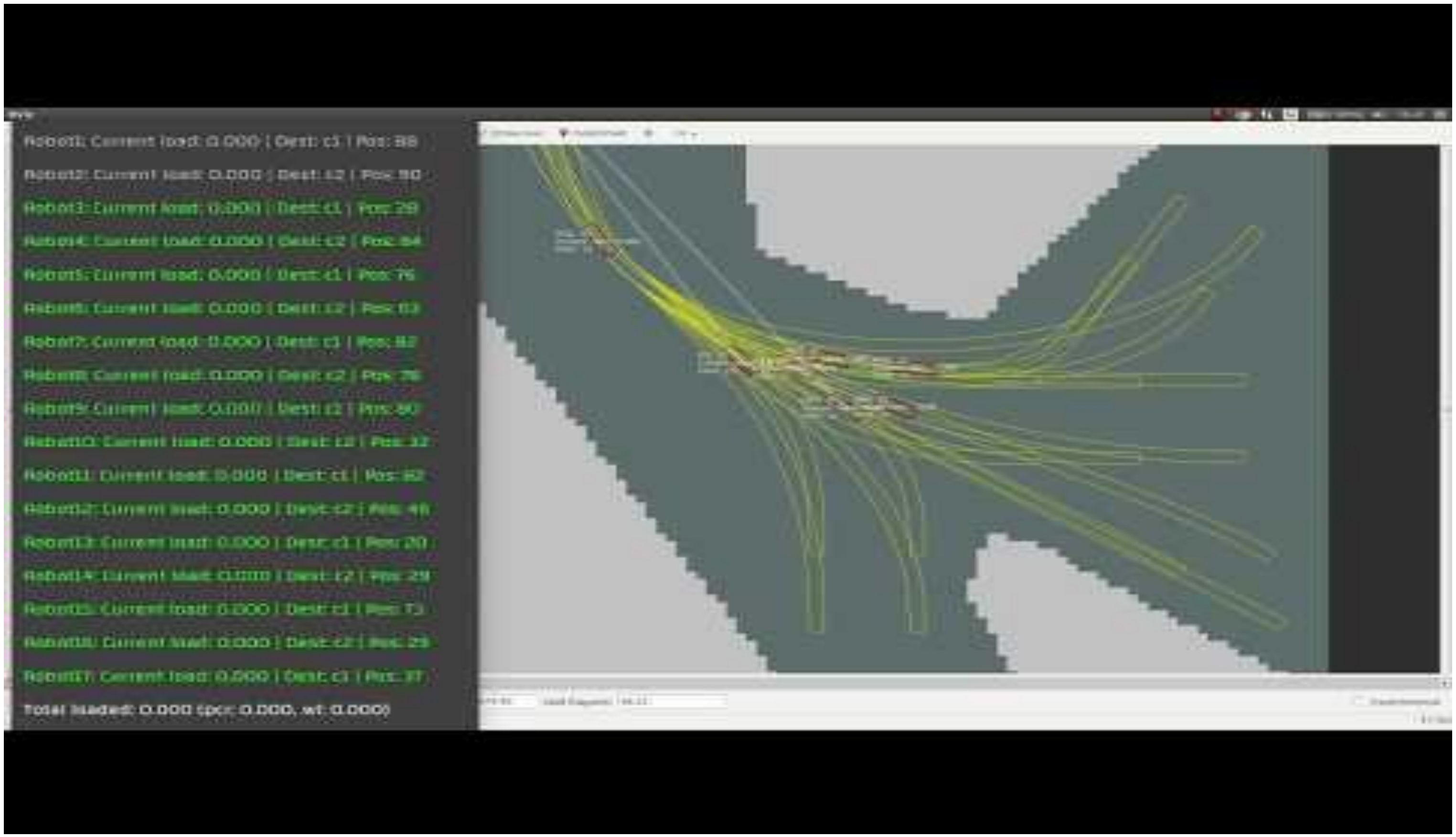


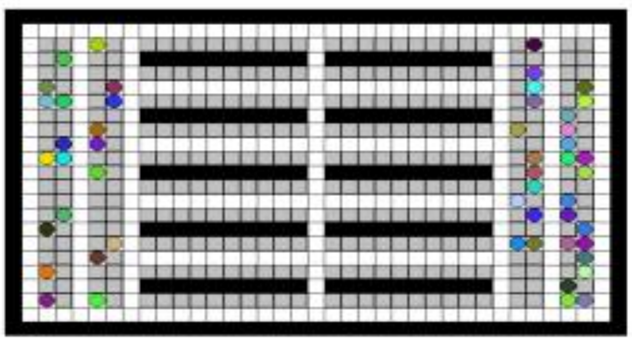
# Integrated Coordination, Motion Planning and Control in a construction site

F. Pecora, H. Andreasson, M. Mansouri, V. Petkov (2018). "A Loosely-Coupled Approach for Multi-Robot Coordination, Motion Planning, and Control". In Proc. of Int Conf on Automated Planning and Scheduling (ICAPS 2018)]



# Considerations

- Q3: (Specifying Versus Learning)
- Q5: (Planning With Uncertainty)

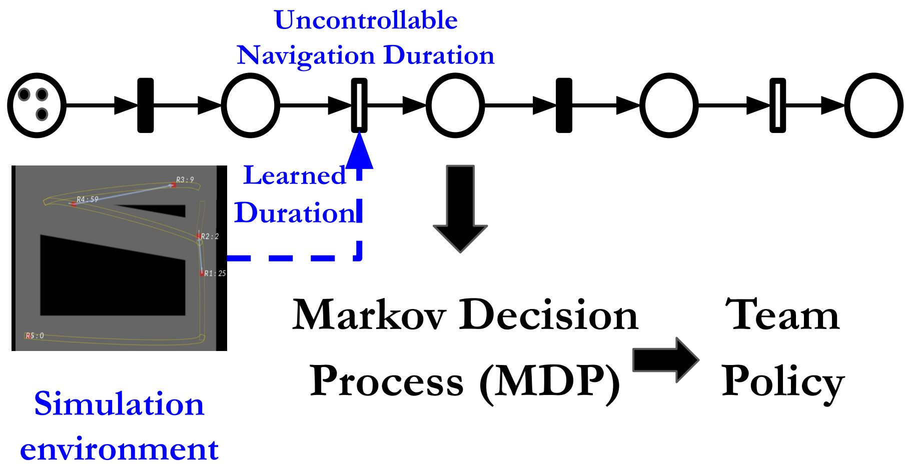


**Amazon-like warehouses**

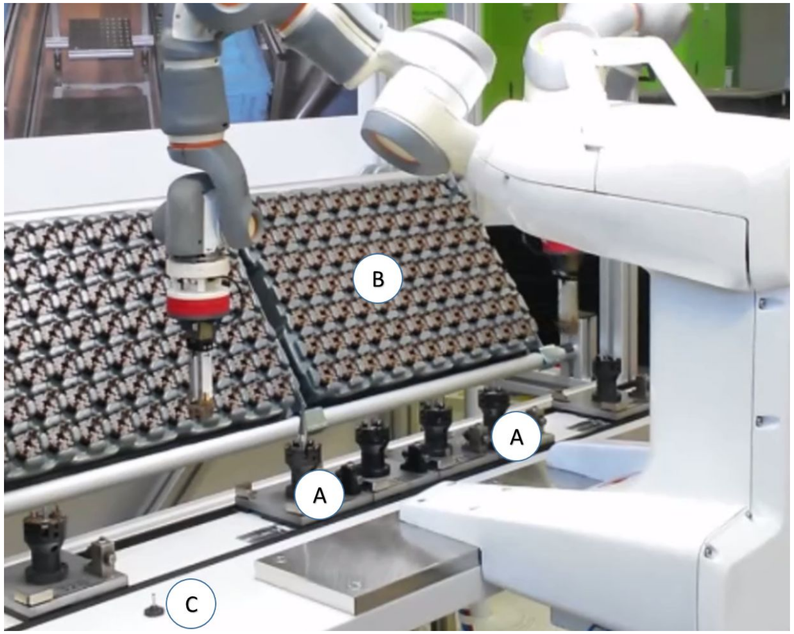
Lifelong Multi-Agent Path Finding for Online Pickup and Delivery Tasks, Hang Ma et. al, AAMAS 2017

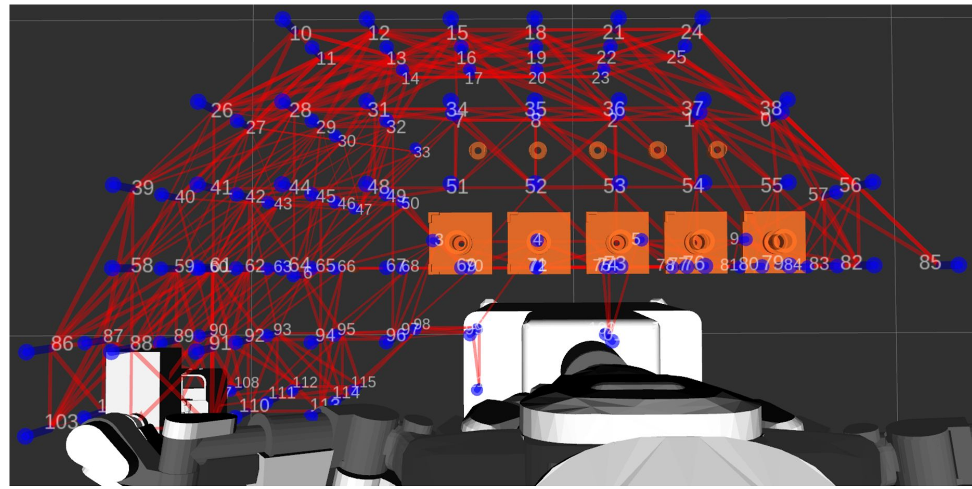
**Secondary crusher**

**manually** produce gravel via Wheel Loader



# Assembly planning for industrial manipulators



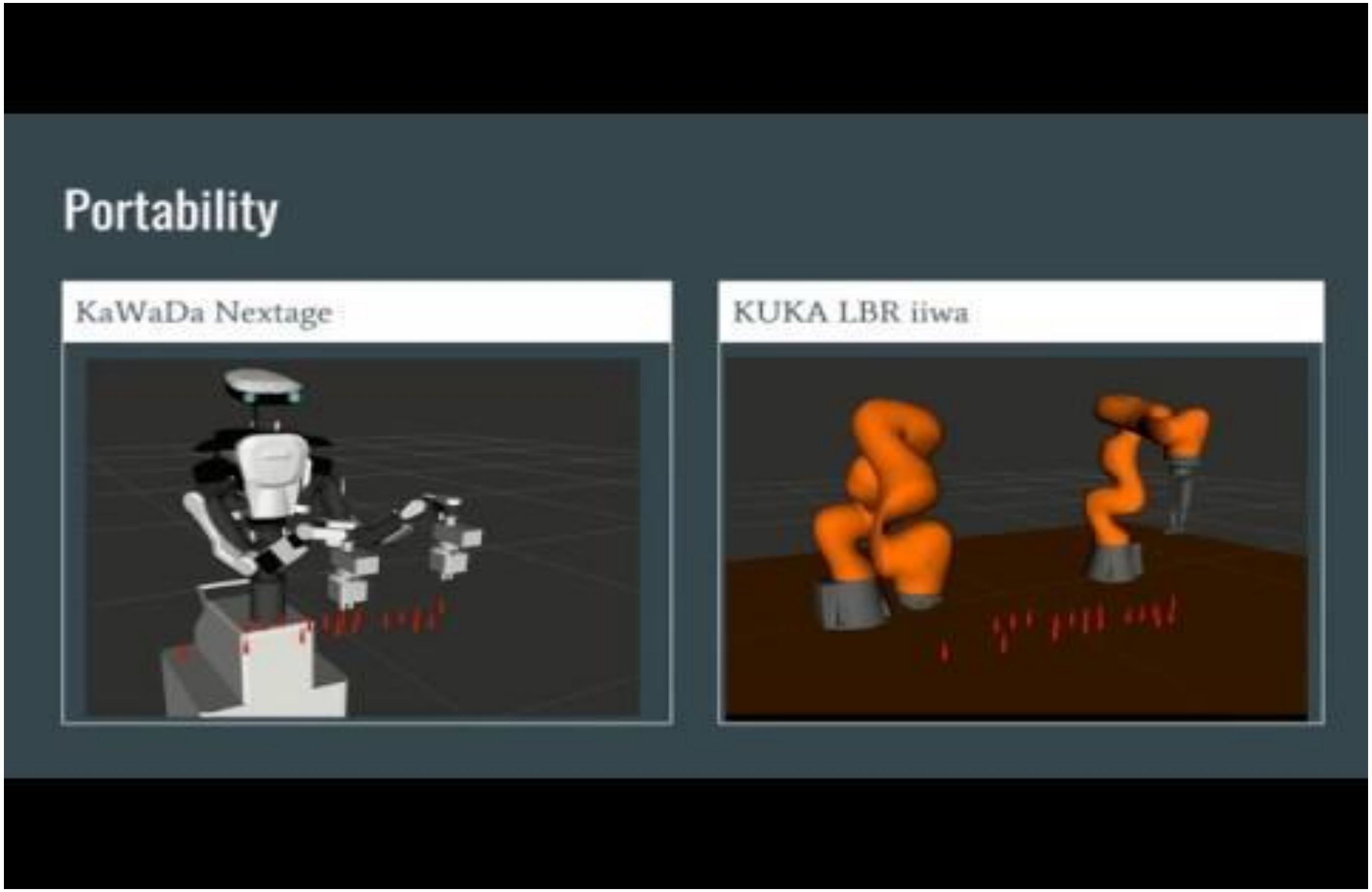



Assembling of wiper motors

**Problem:** Simultaneous Task Allocation and Motion Scheduling for Industrial Dual-Arm Manipulation Tasks

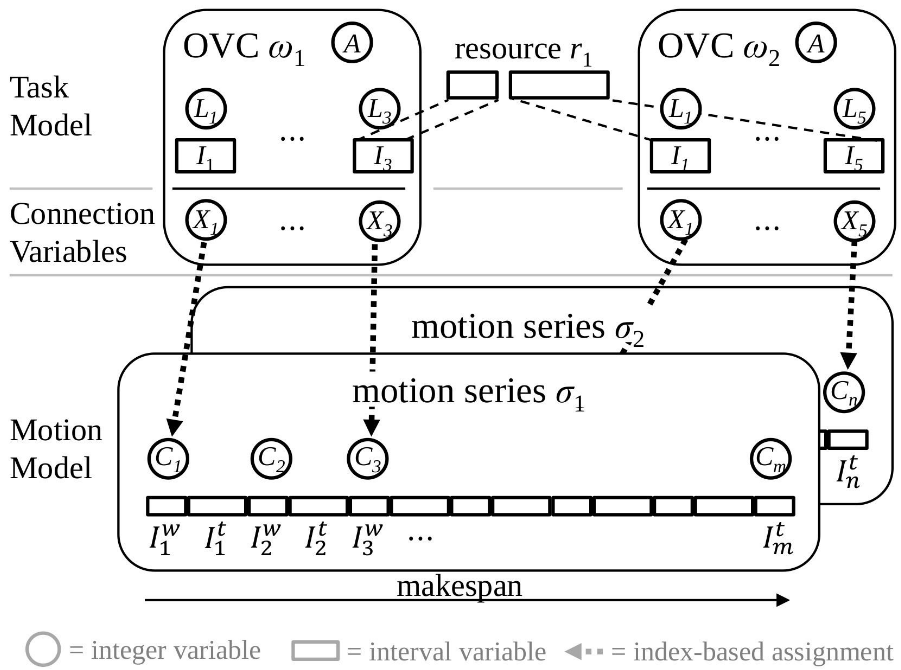
# Assembly planning for industrial manipulators

[JK Behrens, R Lange, M Mansouri, International Conference on Robotics and Automation (ICRA), 2019]



# Considerations

- Q1: (Abstraction)
- Q2: (Symbolic Versus Continuous Models)
- Q5: (Planning With Uncertainty)

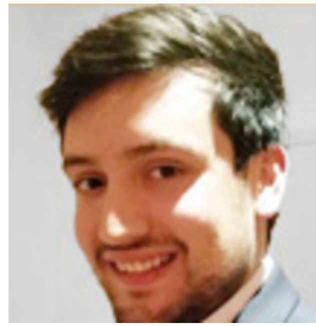


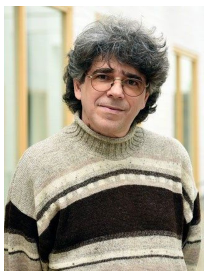
# Good practices

- Analysing the types of **uncertainty**
- Determining **the levels of abstraction**, and an effective method for their incorporation
- **Discretize** the problem space

# Acknowledgments







Thank you!