SAGL: A NEW HEURISTIC FOR MULTI-ROBOT ROUTING WITH COMPLEX TASKS

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AGENDA

- Complex Routing Problem (CRP)
- Our algorithm: SAGL
- Experimental evaluation: SAGL vs others

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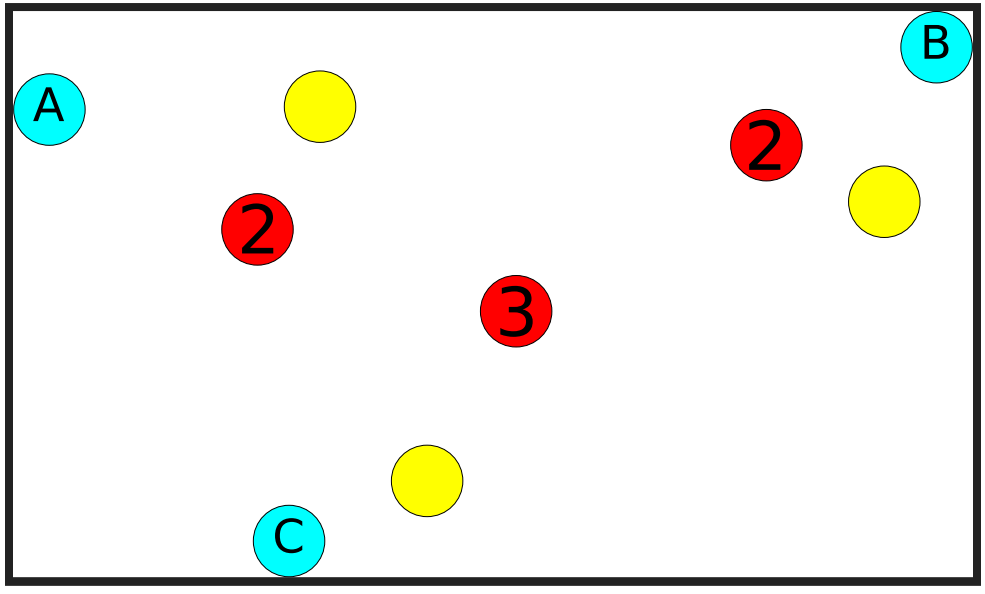
MOTIVATION

Search-and-rescue: lifting heavy debris (source: https://www.fema.gov/media-library/assets/images/100223)

COMPLEX ROUTING PROBLEM (CRP)

- Multiple homogeneous robots
  - same moving speed
  - same ability to accomplish tasks
- Multiple tasks in different locations
- Some tasks require more than one robots to accomplish
- Cooperative settings
- Solution: Task visitation order for each robot
- Solution evaluation: Makespan (total time required to accomplish all tasks)

COMPLEX ROUTING PROBLEM EXAMPLE



- Cyan: robots
- Yellow: tasks requiring only 1 robot (simple tasks)
- Red: tasks requiring N robots ($N \geq 2$) (complex tasks with a complexity level of N)
- Reduces to TSP-Path if only one robot and no complex tasks.

- State-of-the-art: Approach with Reaction Functions (ARF) [Zheng et al. '08, '11]
  - Based on auction mechanism
  - Produces good solution
  - Does not scale
    - e.g., cannot solve 20 complex tasks with a complexity level of 2 within 1 hour
- SAGL
  - Produces decent solution
  - Polynomial time complexity and scalable
    - Can handle high complexity levels and a large number of complex tasks

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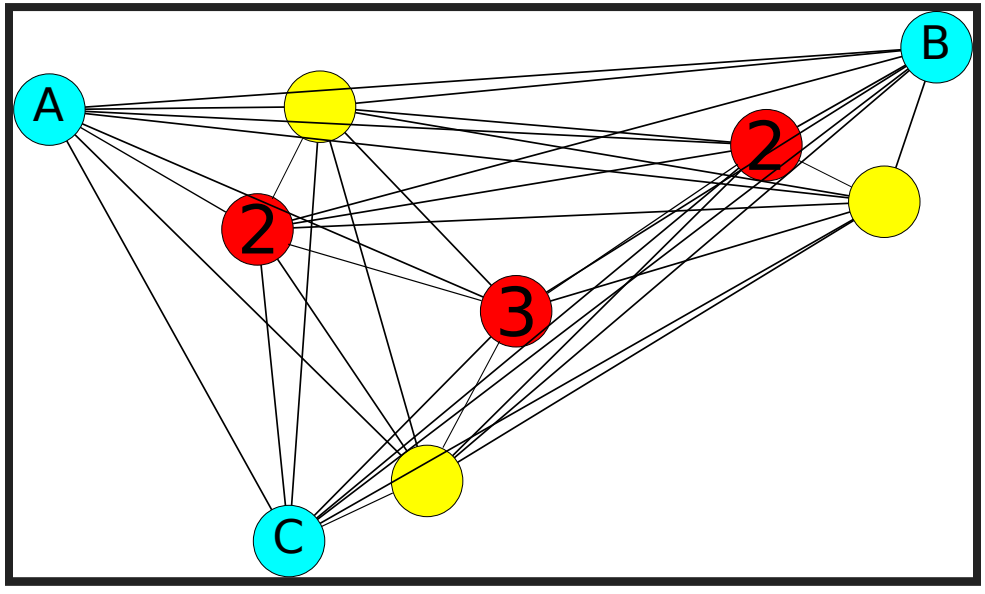
EMBED COMPLEX ROUTING PROBLEM INTO A GRAPH



We embed a problem instance into
a **complete undirected edge-weighted graph**

- Vertices represent task and robot initial locations.
- Edges represent distances between the locations.

ASSUMPTIONS

- No collisions between robots.
- Distances satisfy the triangle inequality.
- Distances are symmetric.
- All robots move with unit speed.
- All tasks are accomplished immediately once all robots arrive—time span required for accomplishing tasks can be amortized into the incident edges.

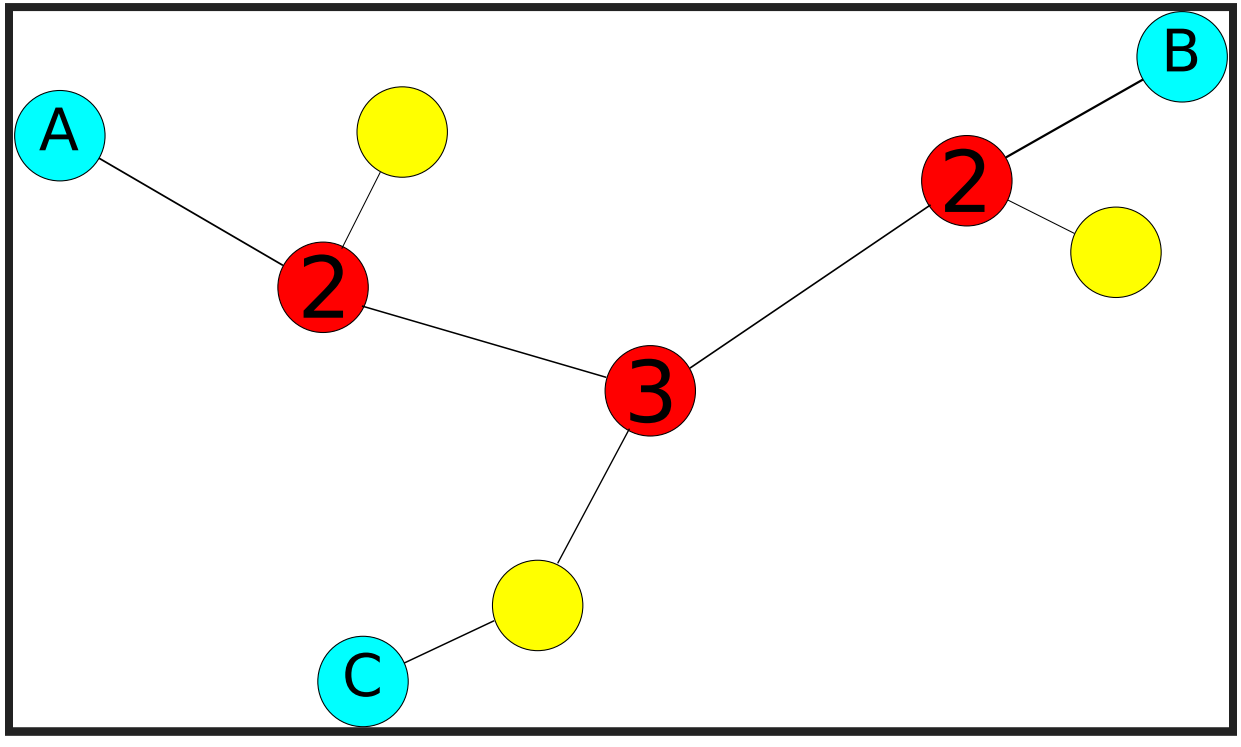
SAGL OVERVIEW

- Which robots should visit which tasks
  1. Spanning tree construction
  2. Task assignment
- What visitation order should the robots use
  3. Global visitation order determination for complex tasks
  4. Local visitation order determination

WHICH ROBOTS SHOULD VISIT WHICH TASKS

1. Spanning tree construction
    - Provides a base for task assignments
2. Task assignment

CONSTRUCT THE SPANNING TREE



Provides a base for task assignments:
inspired by 2-approximation TSP

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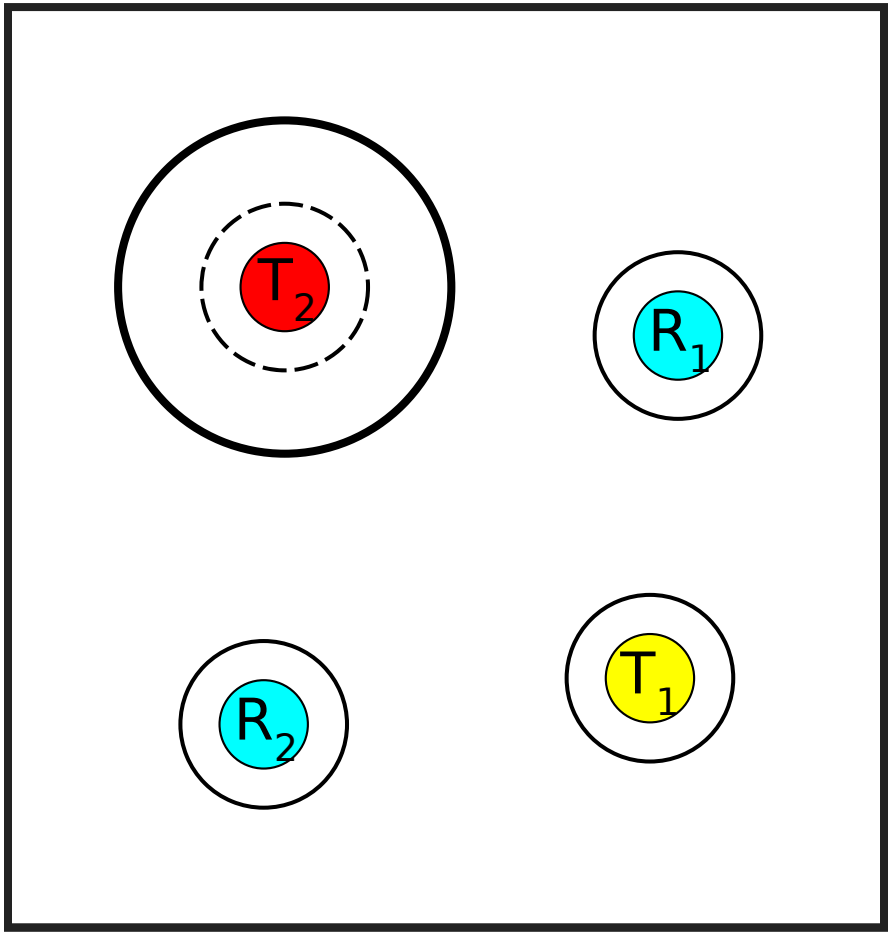

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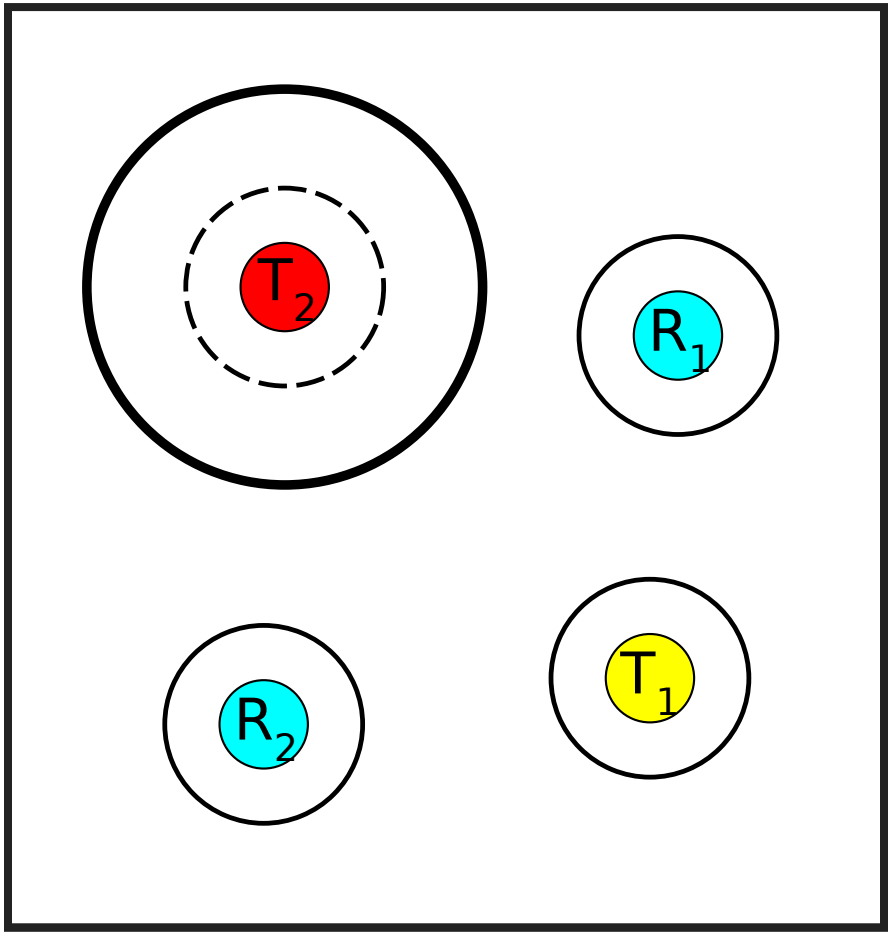

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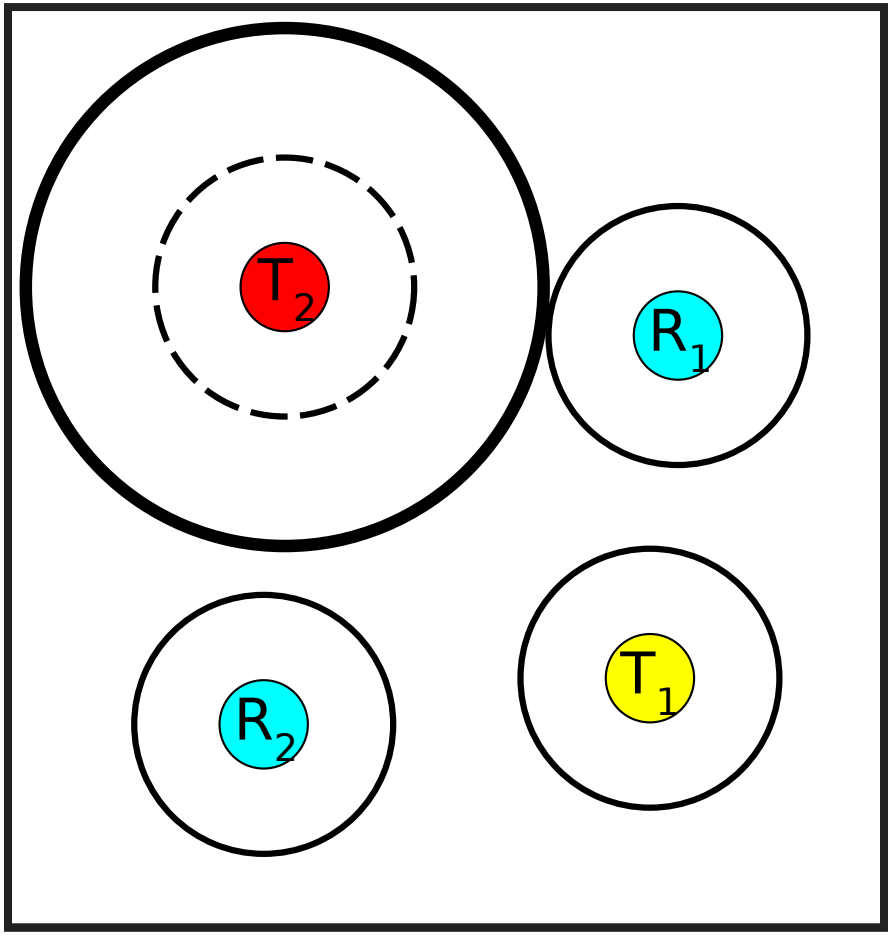

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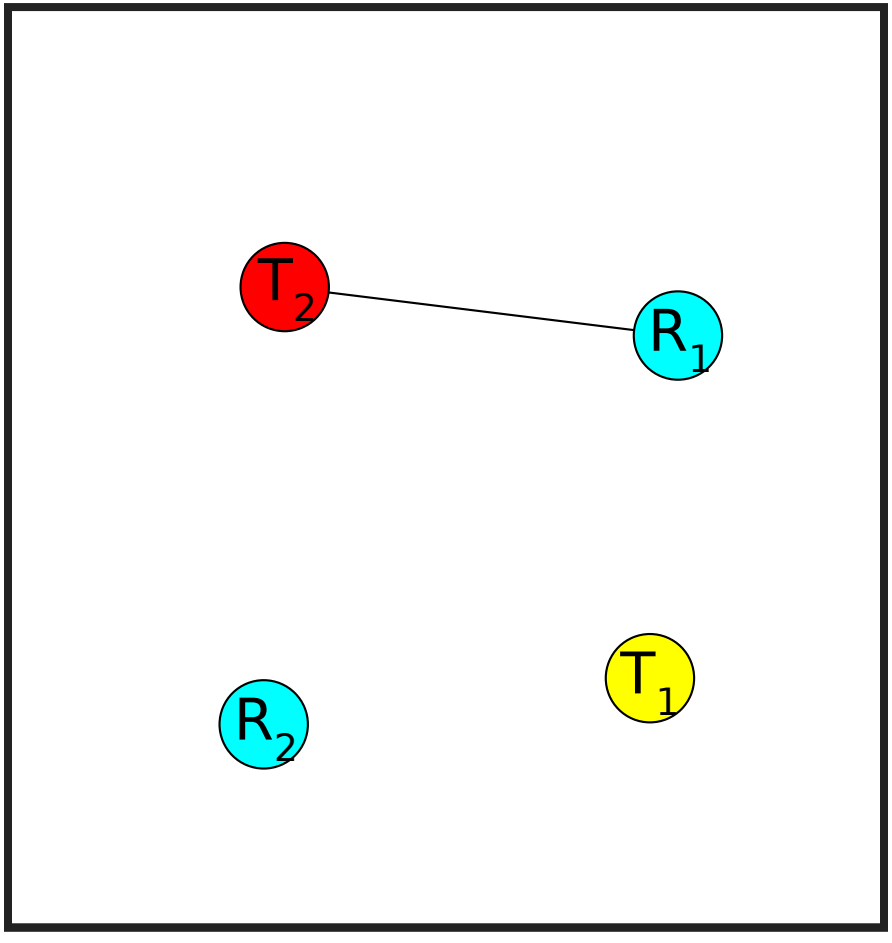

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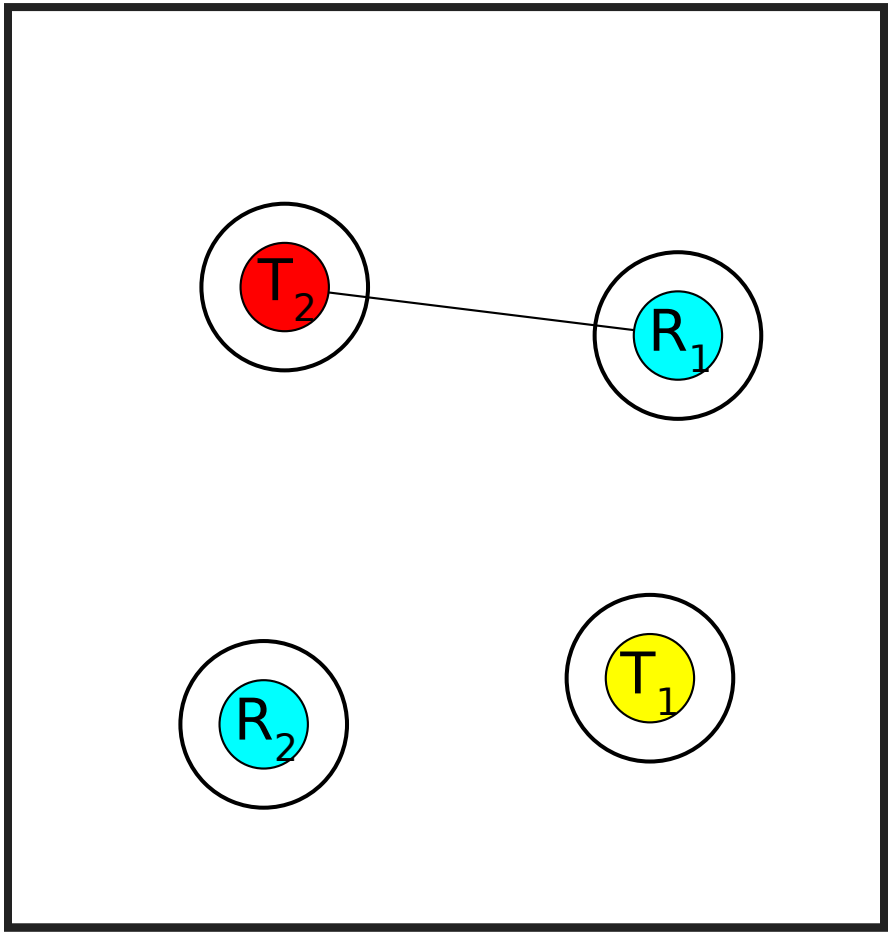

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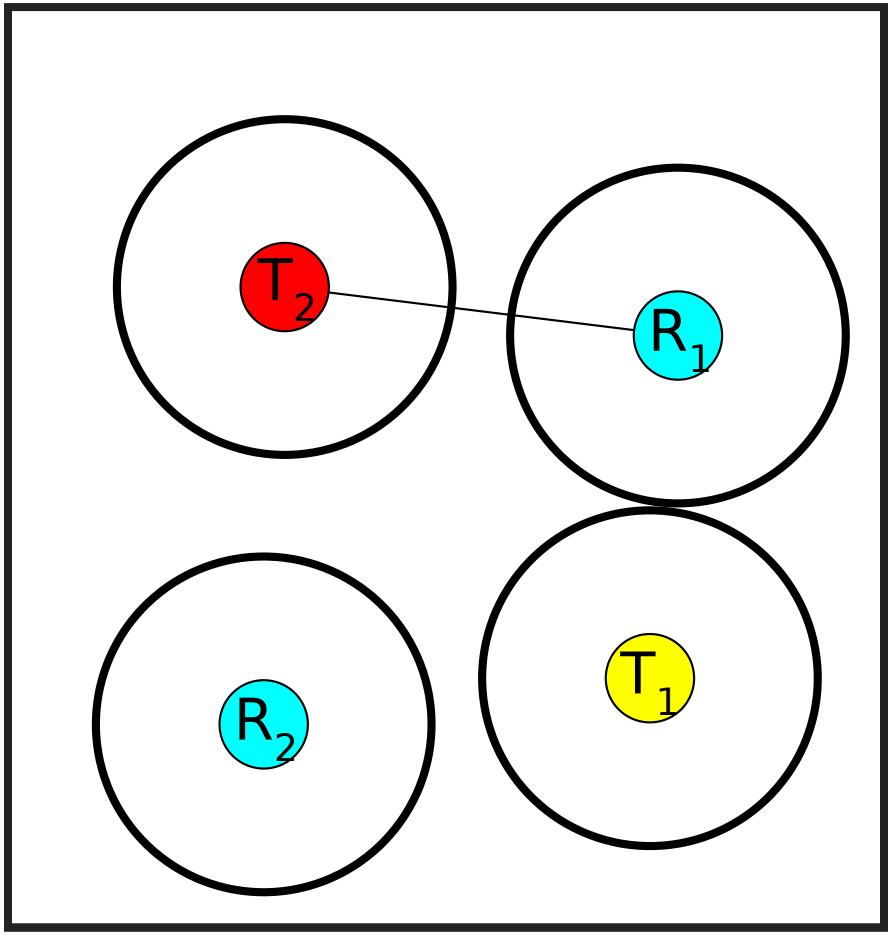

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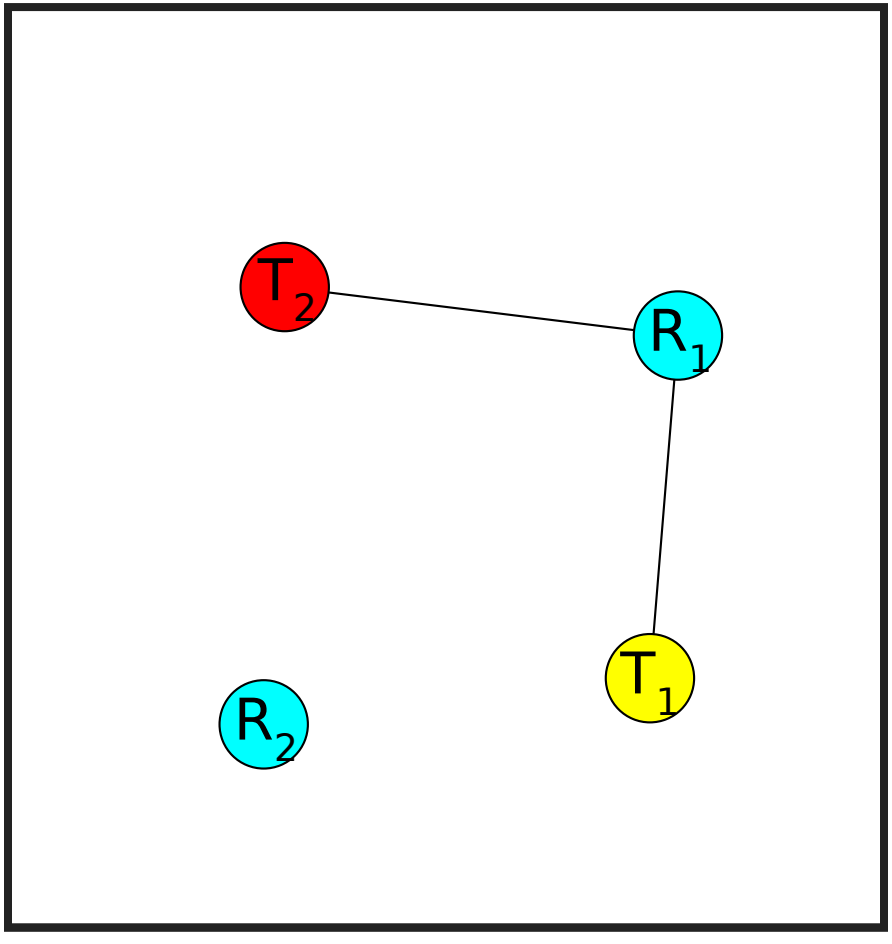

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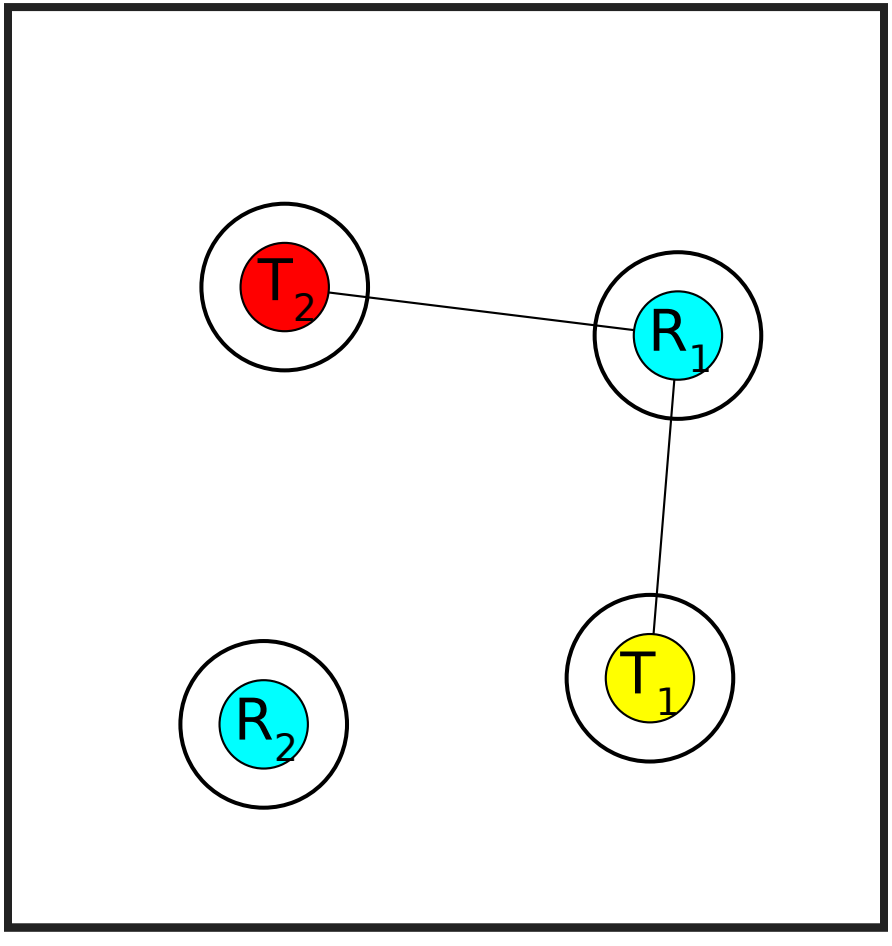

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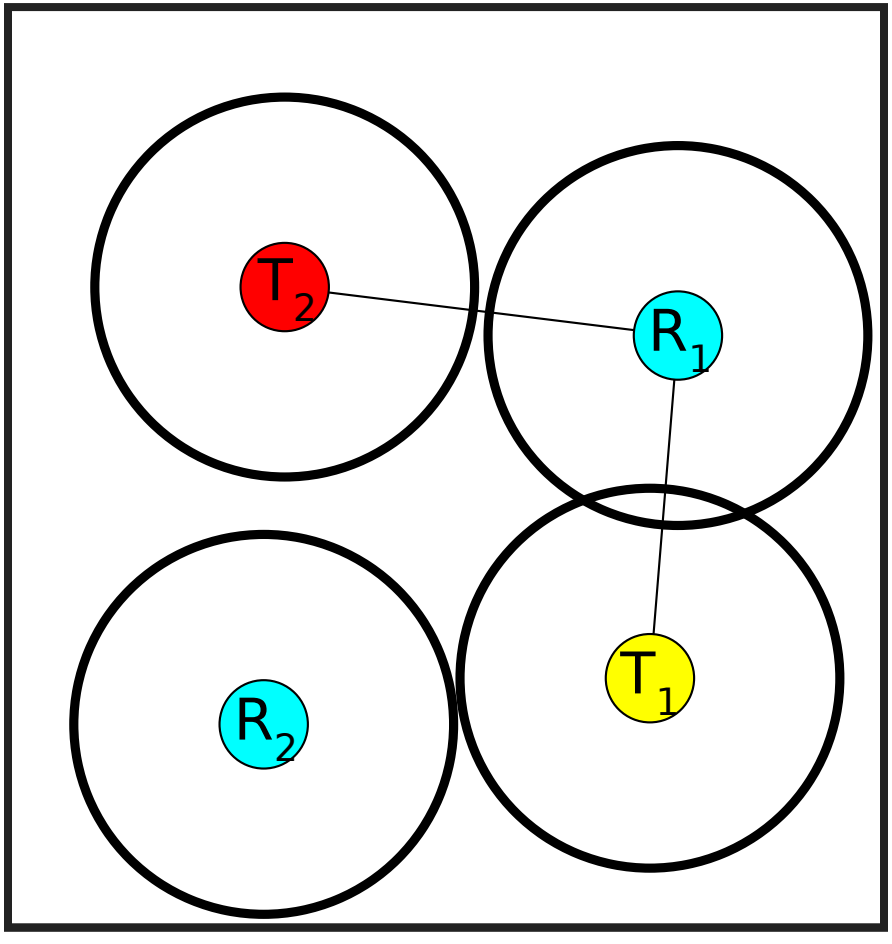

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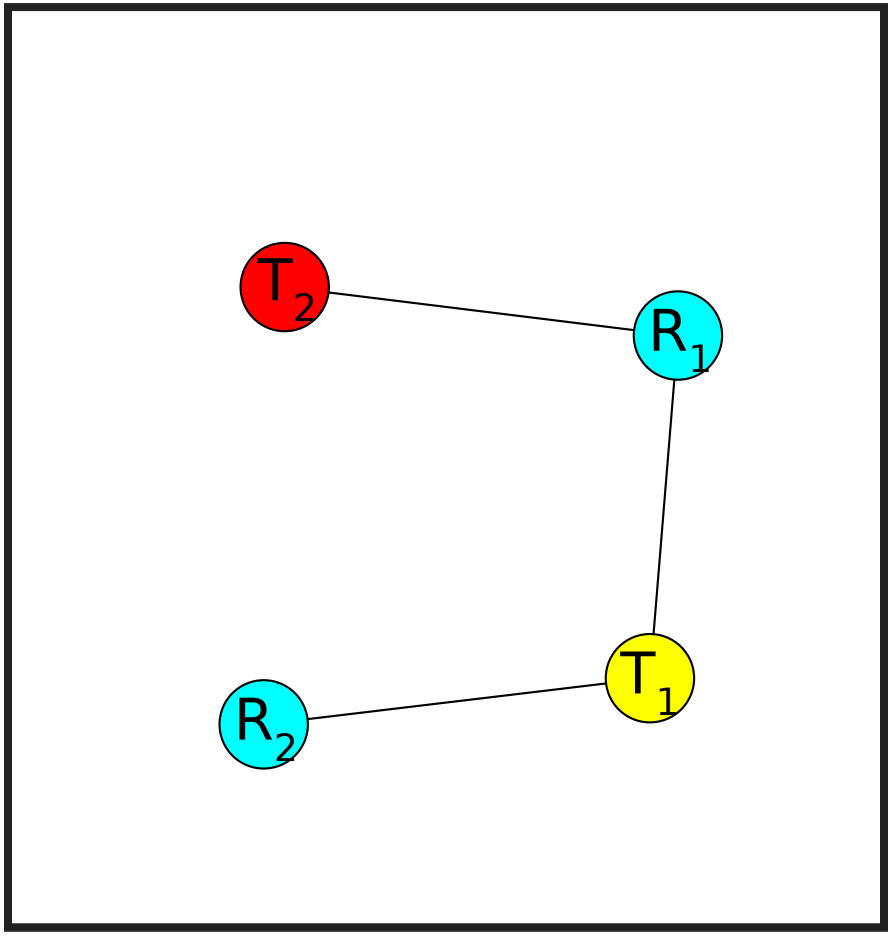
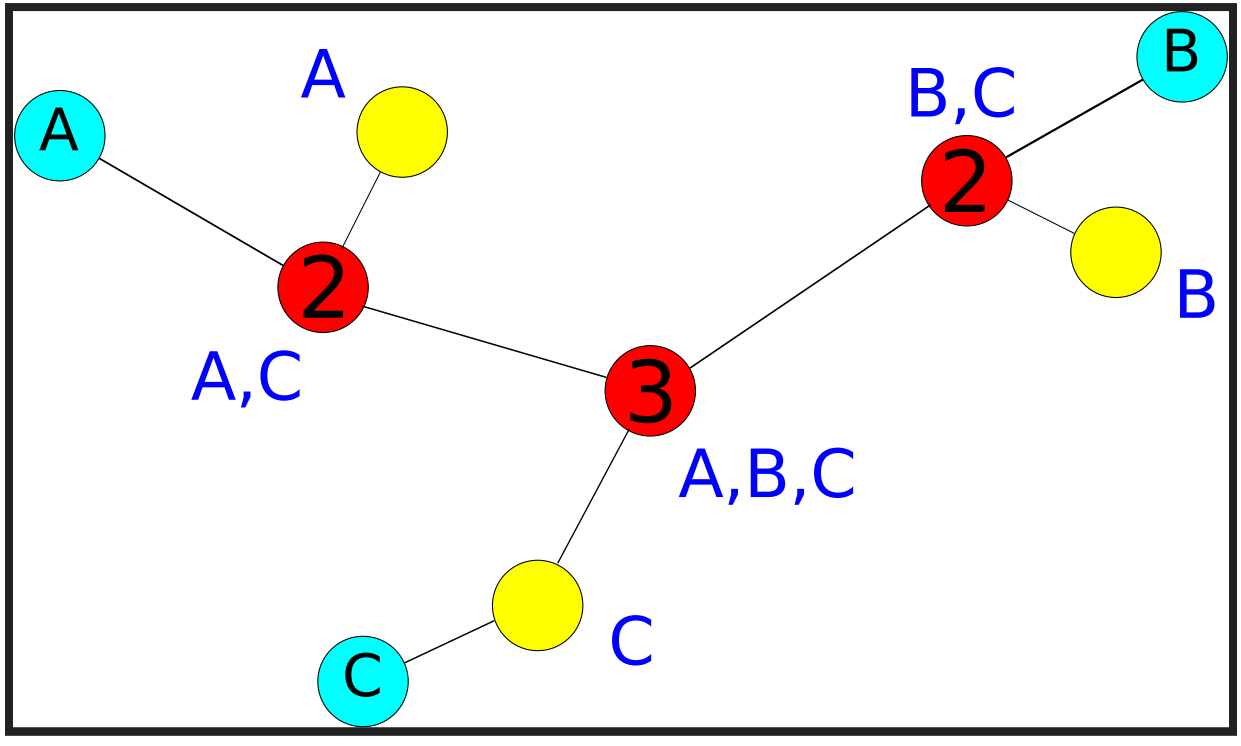


ASSIGN TASKS TO ROBOTS

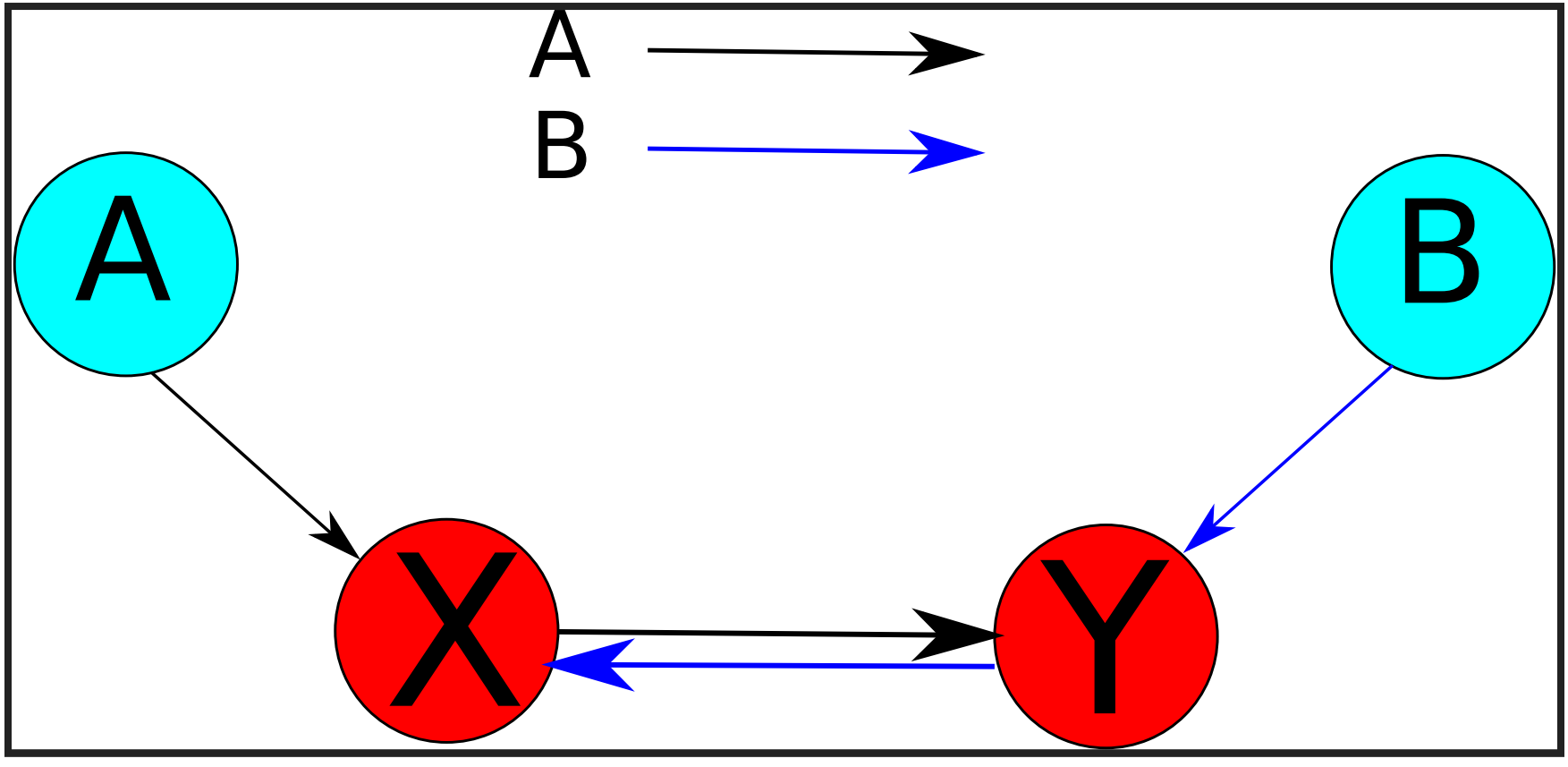


According to the distances on the spanning tree.

WHAT VISITATION ORDER SHOULD THE ROBOTS USE

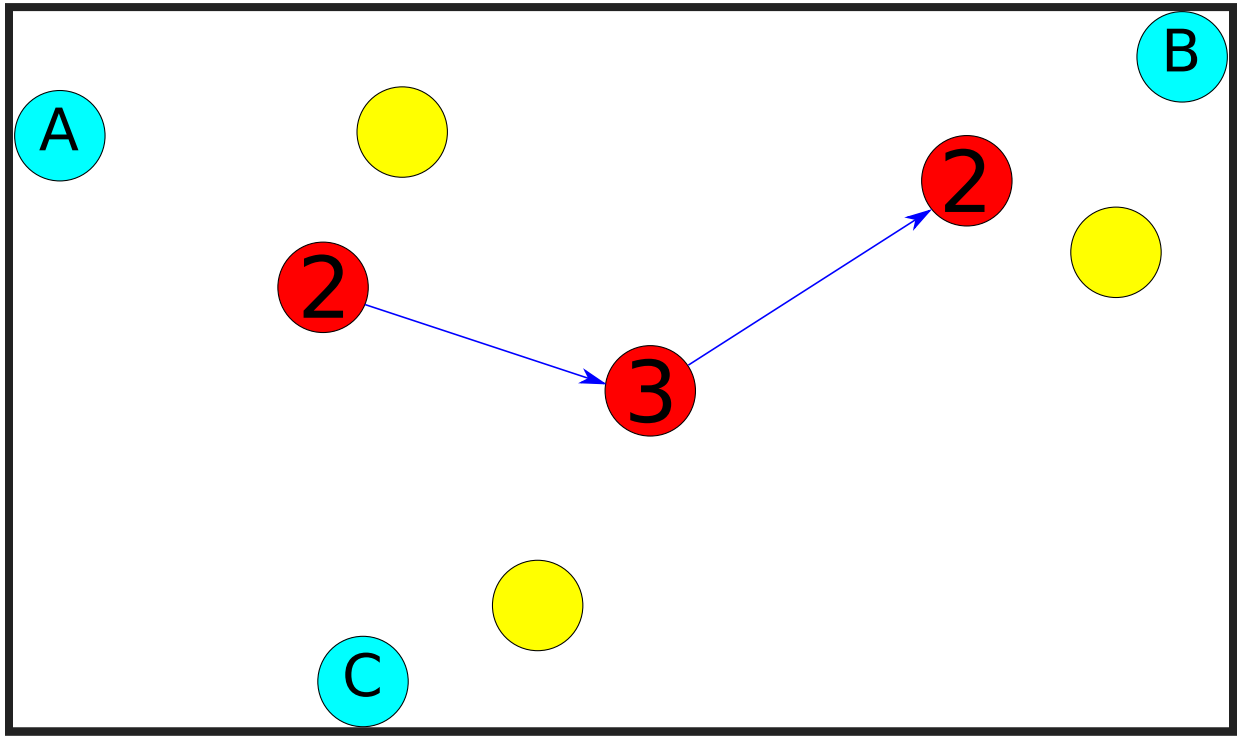
1. Global visitation order determination for complex tasks
    - Prevent deadlocks
2. Local visitation order determination

DEADLOCKS



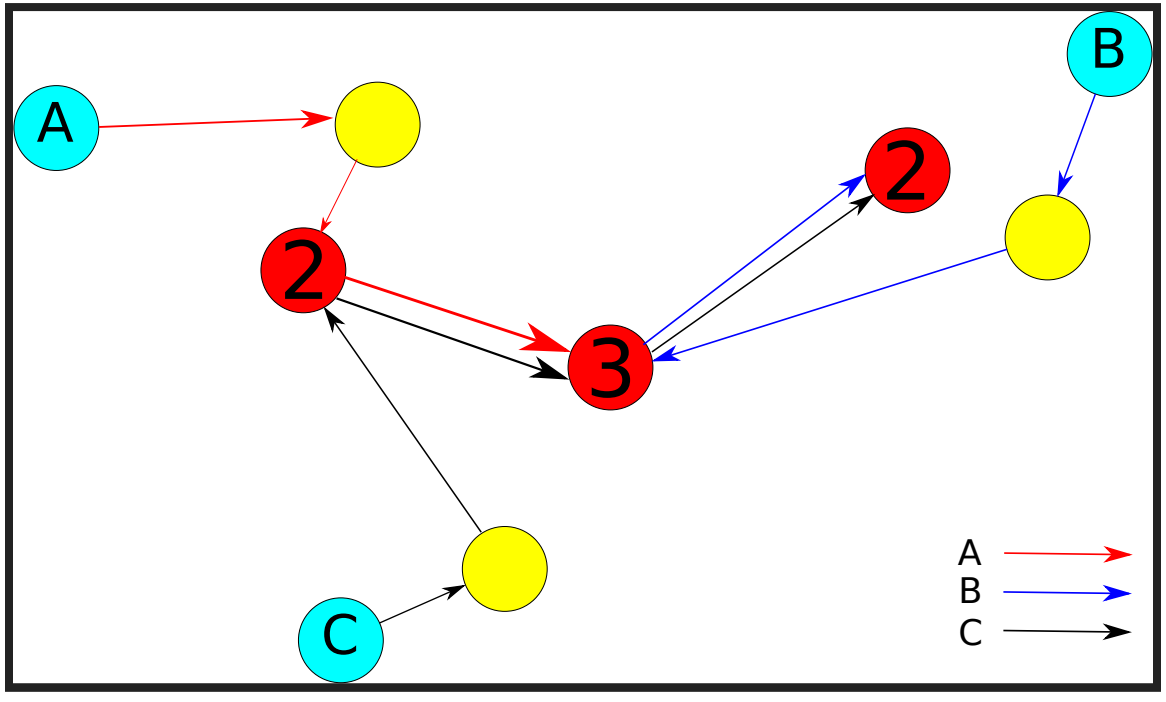
- Robot A waits at X forever.
- Robot B waits at Y forever.

GLOBAL VISITATION ORDER OF COMPLEX TASKS



Prevent deadlocks

LOCAL VISITATION ORDER



Path-constrained TSP [Bachrach et al. '05]:
Consistent with the global visitation order

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EXPERIMENT SET 1

- Compared with Approach with Reaction Functions (ARF) [Zheng et al. '08, '11]
- Map: 51x51 grid office environment
- 200 CRP instances with random vertices for
  - 10 robots
  - 80 simple tasks
  - various numbers of complex tasks with a complexity level of 2

OFFICE MAP

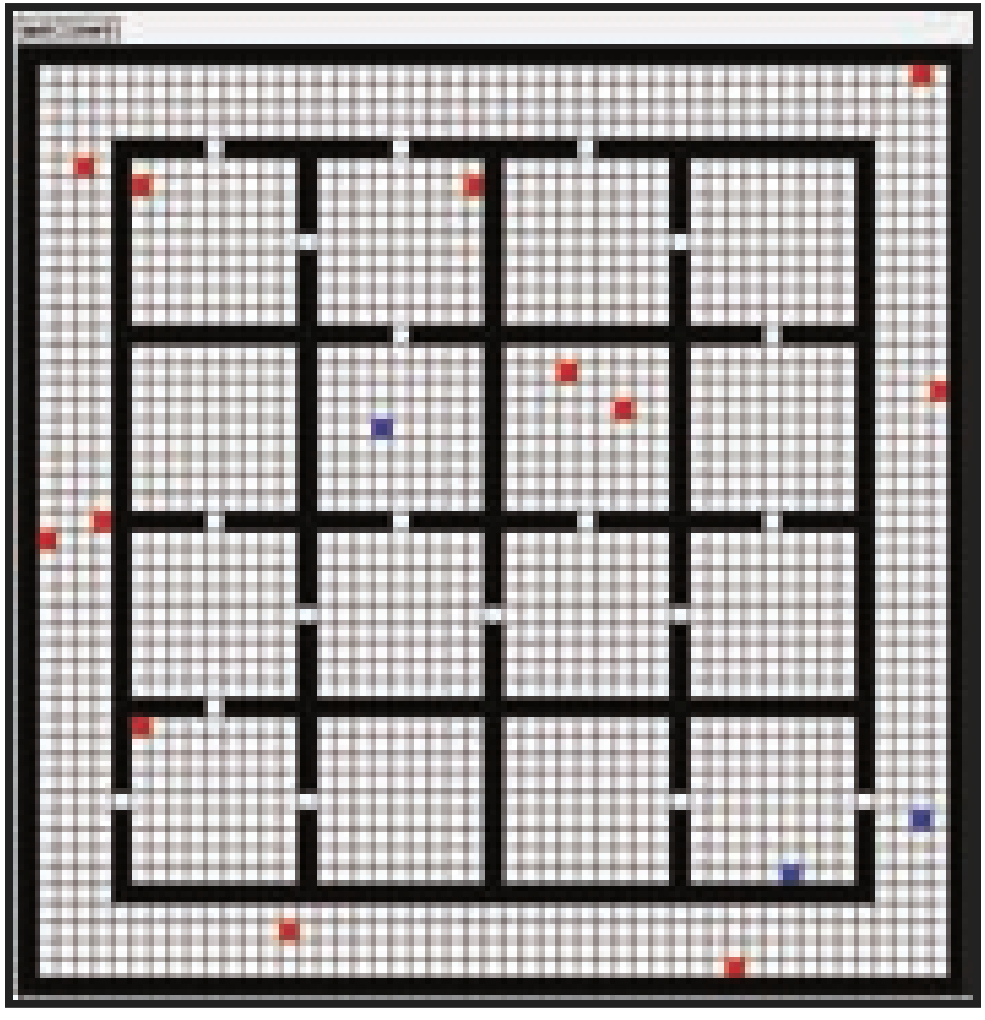
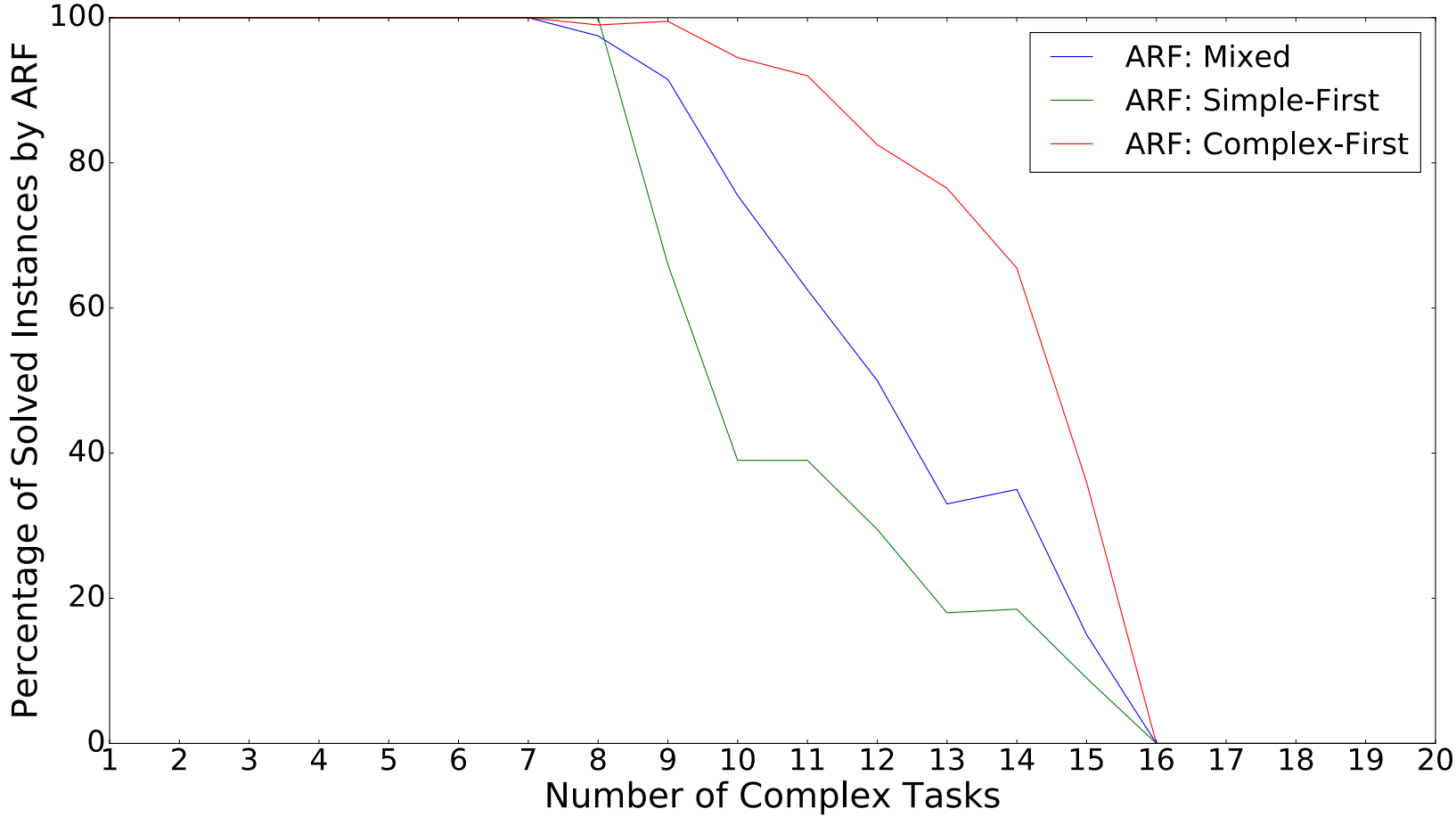


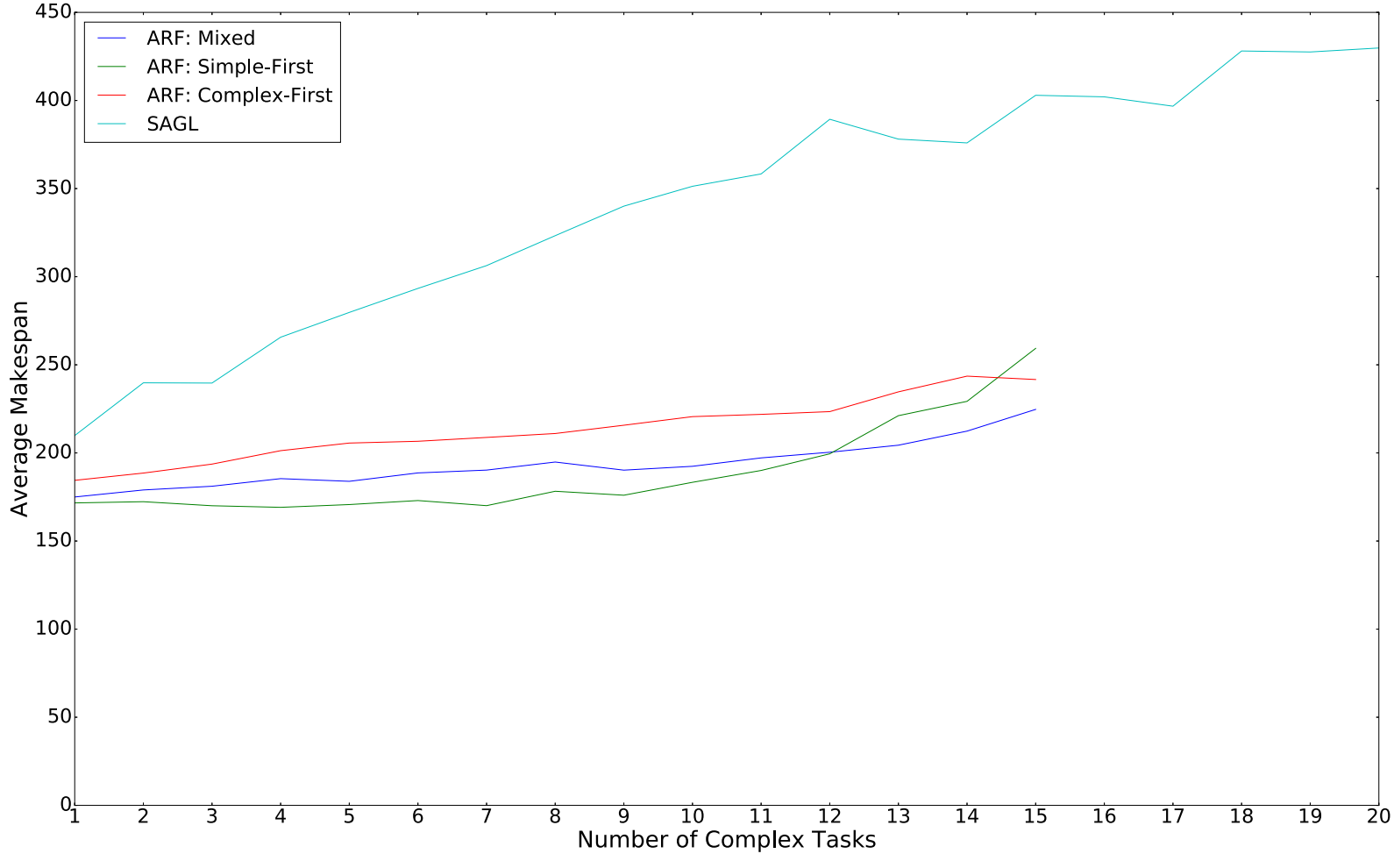
image source: [Koenig et al. '07]

COMPARED WITH ARF: EFFICIENCY



Percentage of instances solved by ARF within 2 minutes.
SAGL solved each of them within one second.

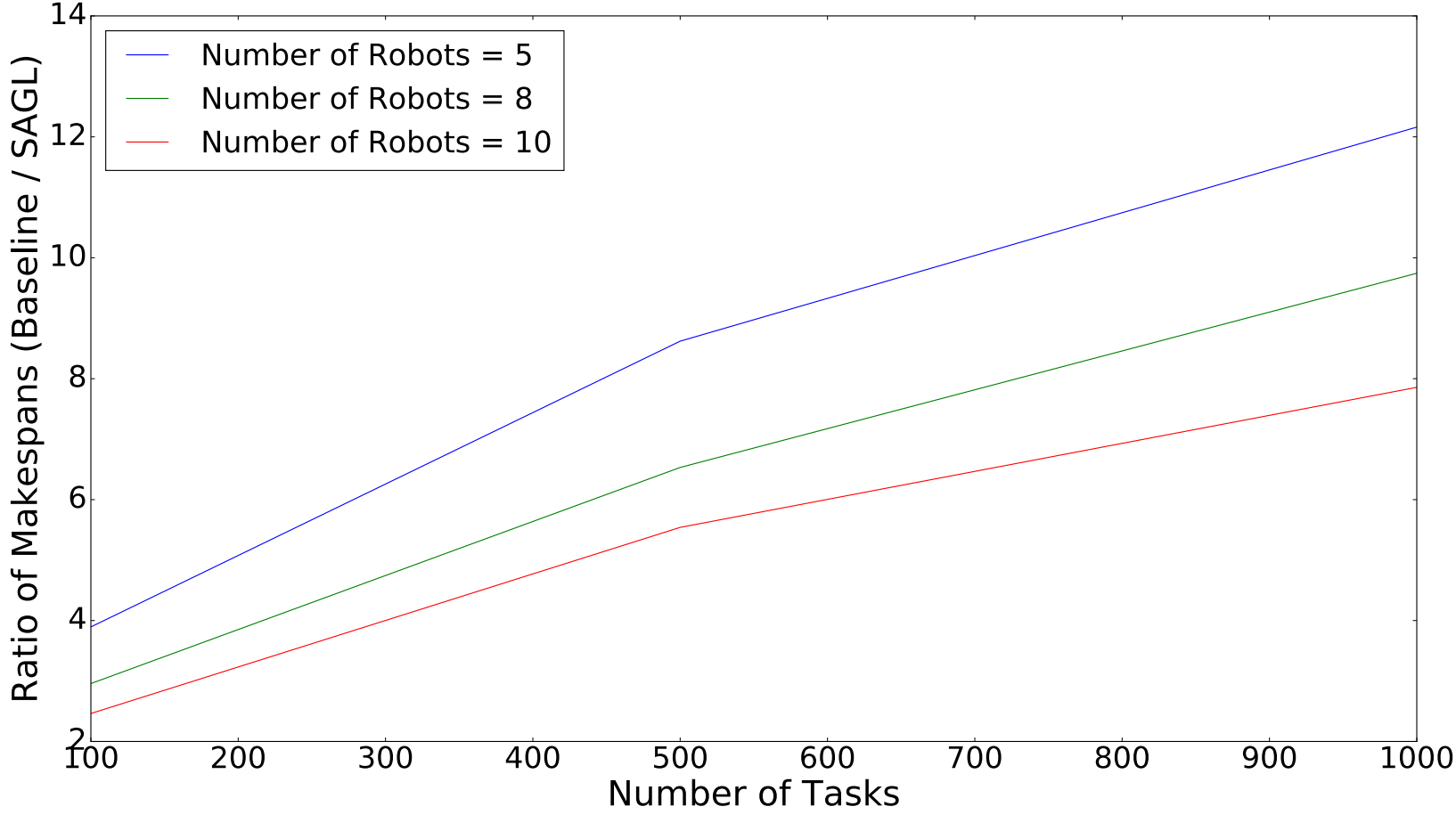
COMPARED WITH ARF: MAKESPAN



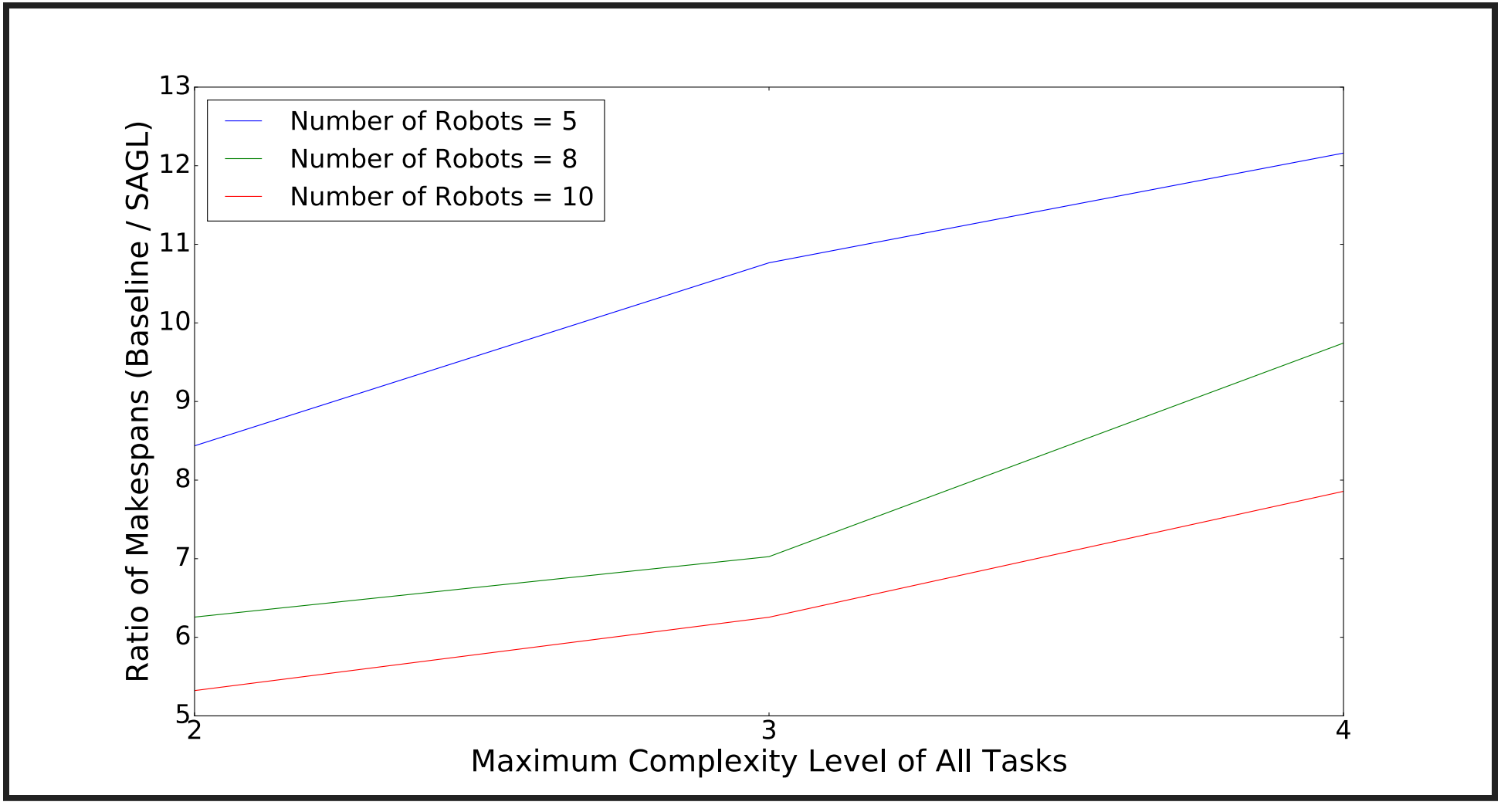
EXPERIMENT SET 2

- Large instances
- ARF cannot solve large instances
- Compared with a baseline algorithm
  - No spanning tree
  - Random global visitation order
  - No use of path-constrained TSP
- Map: obstacle free 300x300 continuous square
- 15 CRP instances for random
  - 5, 8 or 10 robots
  - 100, 500 or 1000 tasks
  - max complexity levels of 2, 3 or 4

SAGL VS BASELINE: MAKESPAN VS NUMBER OF TASKS



SAGL VS BASELINE: MAKESPAN VS MAXIMUM COMPLEXITY LEVELS



FUTURE WORK

- Heterogenous robots
- Distributed version
- Flexible complexity levels (task accomplishment time depends on number of robots)

CONCLUSION

- SAGL is
  - A polynomial time solver for the Complex Routing Problem
  - Four steps:
    1. Spanning tree construction
    2. Task assignment
    3. Global visitation order determination for complex tasks
    4. Local visitation order determination
  - More scalable than ARF
  - decent solution quality