Coalition Coordination for Tightly Coupled Multirobot Tasks with Sensor Constraints

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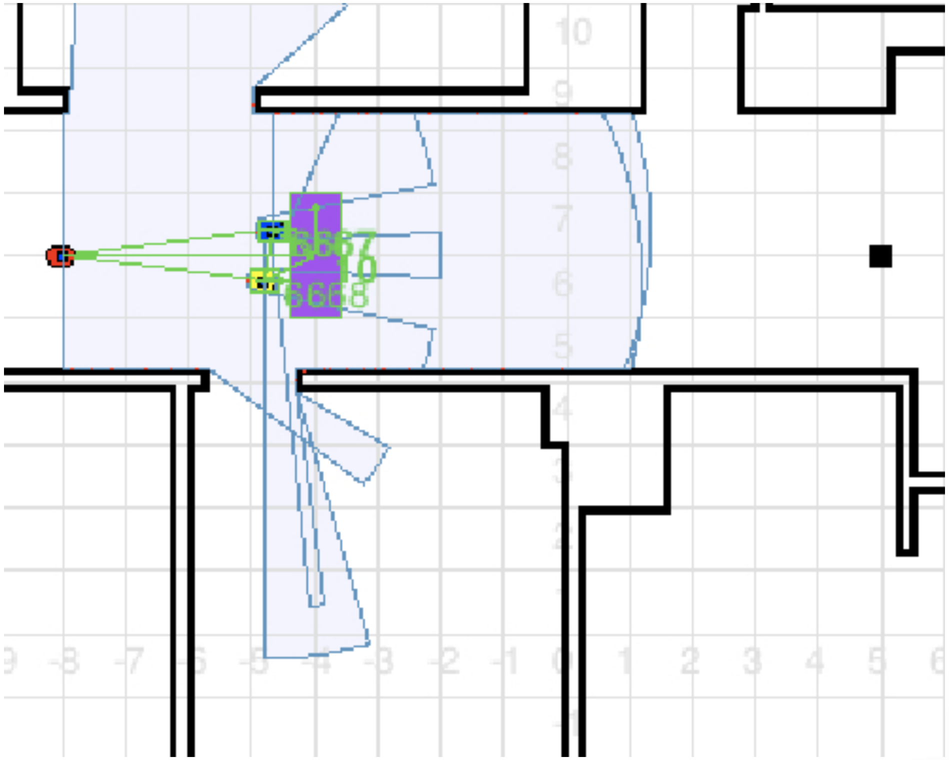
Background

Why coalitions



Background

Before executing coalitions

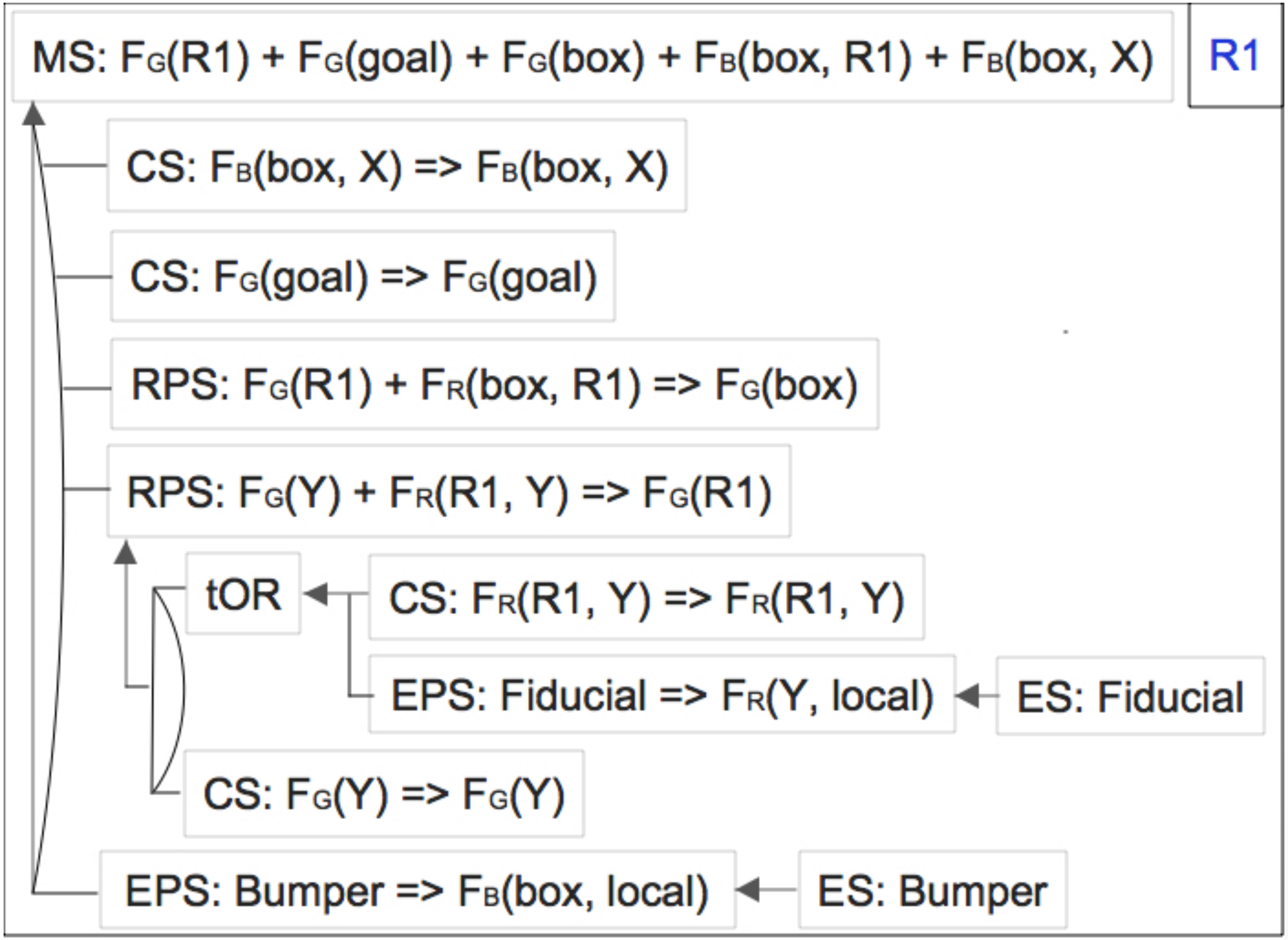
❖ Forming coalitions:

- Previous approaches form coalitions based statically on robot capabilities
- E.g., [Vig and Adams 2006]

- Recent approaches form coalition dynamically based on information flow
- E.g., [Zhang and Parker 2013]

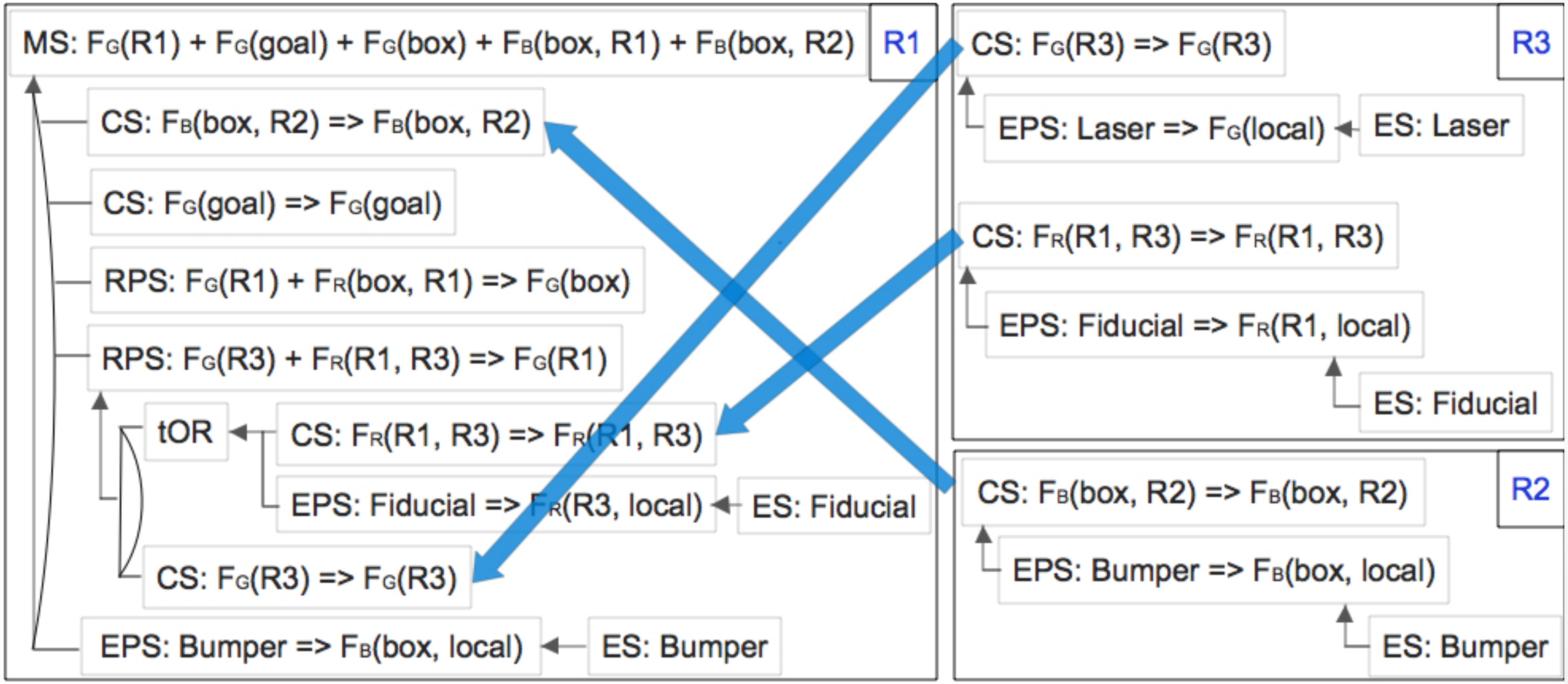
Background

Before executing coalitions



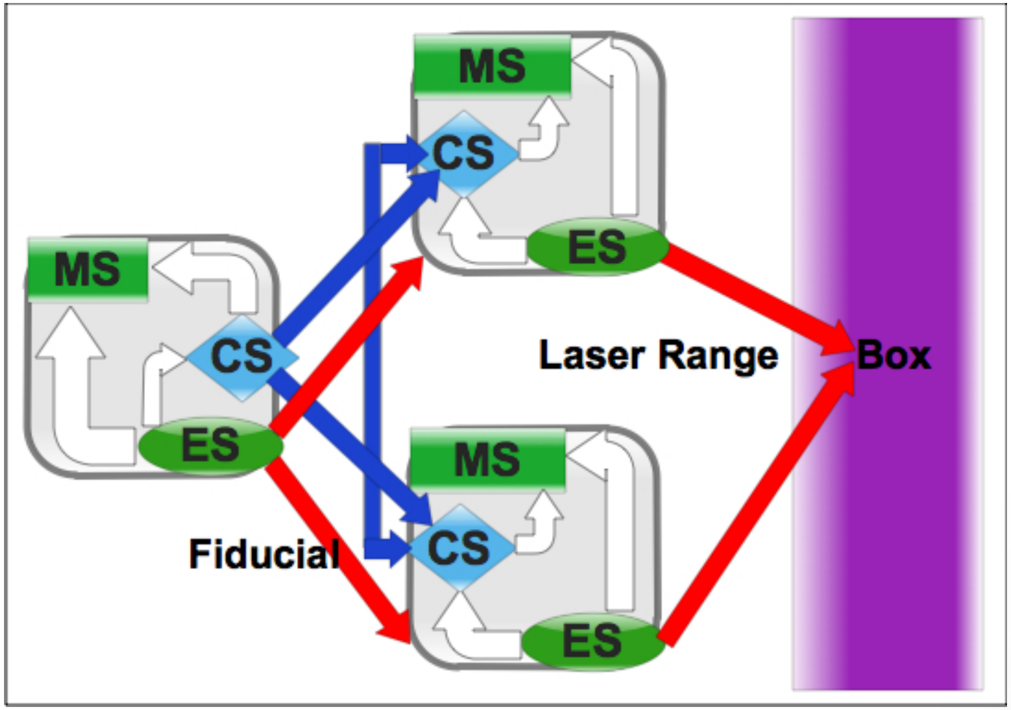
Background

Before executing coalitions



Background

Interactions within coalitions



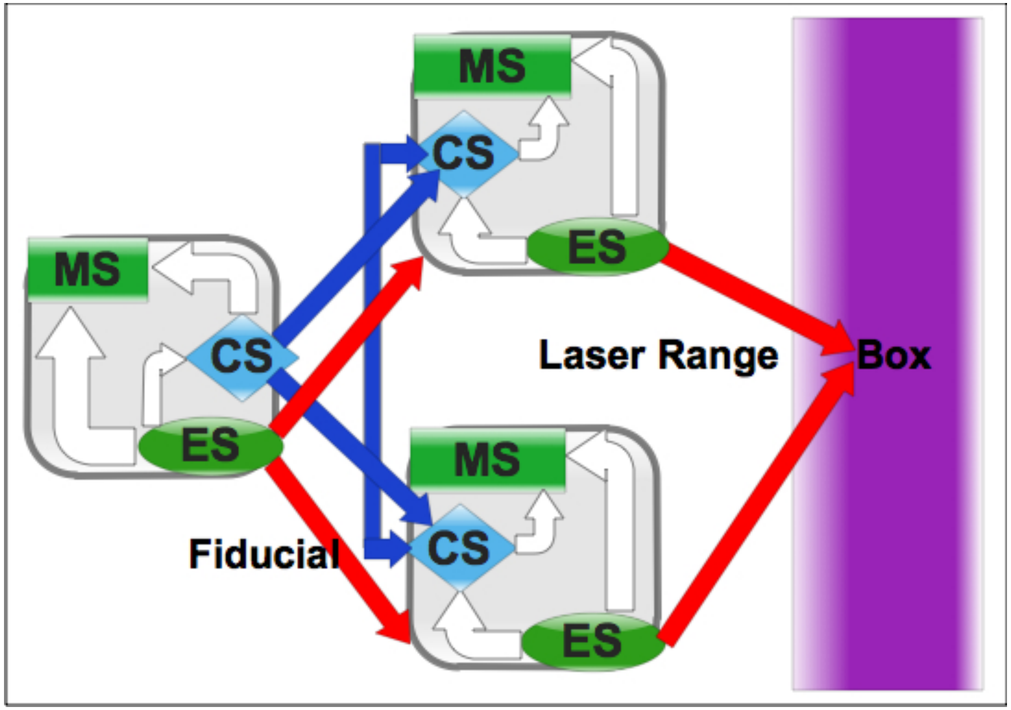
Approach

Coalition coordination

- ➢ Coalitions can overlap
- ➢ Sensor constraints can restrict the robot motion during execution

✧ Coalition coordination is required to reason about synergies between coalitions to enable multitasking

Approach

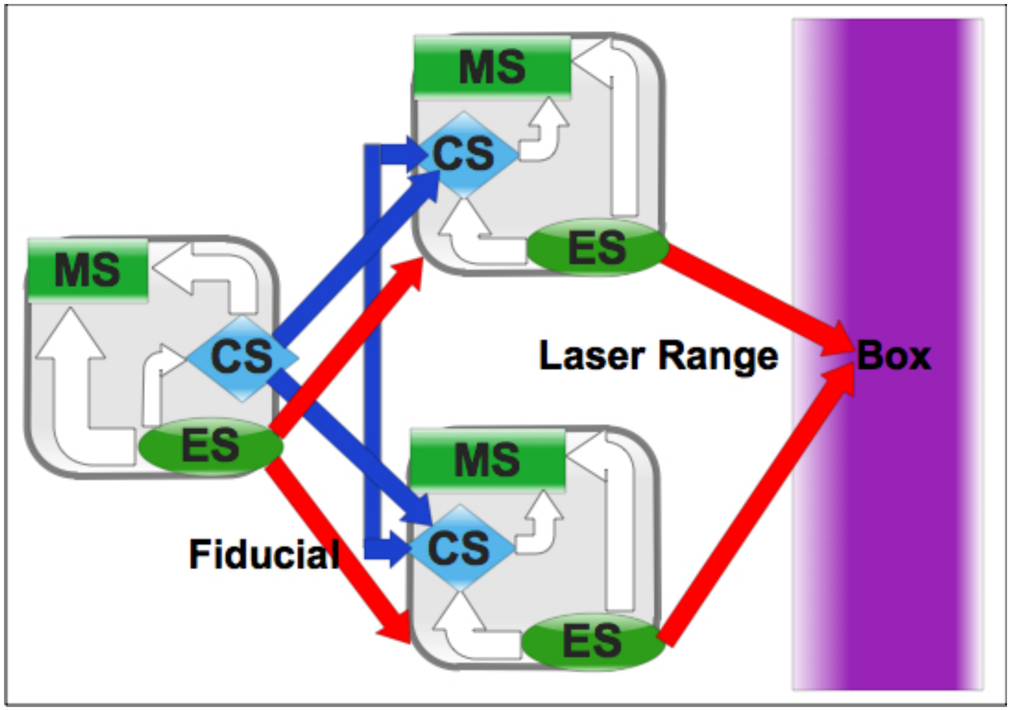


Sensor constraints restrict coalition execution

Definition V.2 (Information Instance). *An information instance, or $F(\mathcal{E})$ (F for short), is an information type with the associated referent set $\mathcal{E}$ ($\mathcal{E}$ is an ordered set). The number of referents or $|\mathcal{E}|$ is determined by the information type.* □

Approach

Coalition coordination



Sensor constraints restrict coalition execution

$$e \rightarrow_{F(\mathcal{E})} \mathcal{E}$$

Definition V.3 (Information Configuration). *The information configuration of an information instance F, denoted by $cf(F)$, represents the set of semantic configurations of the associated referents that are included in the specification of F.* □

Approach

✧ How to maintain a sensor constraint:

$$e \rightarrow_{F(\mathcal{E})} \mathcal{E}$$

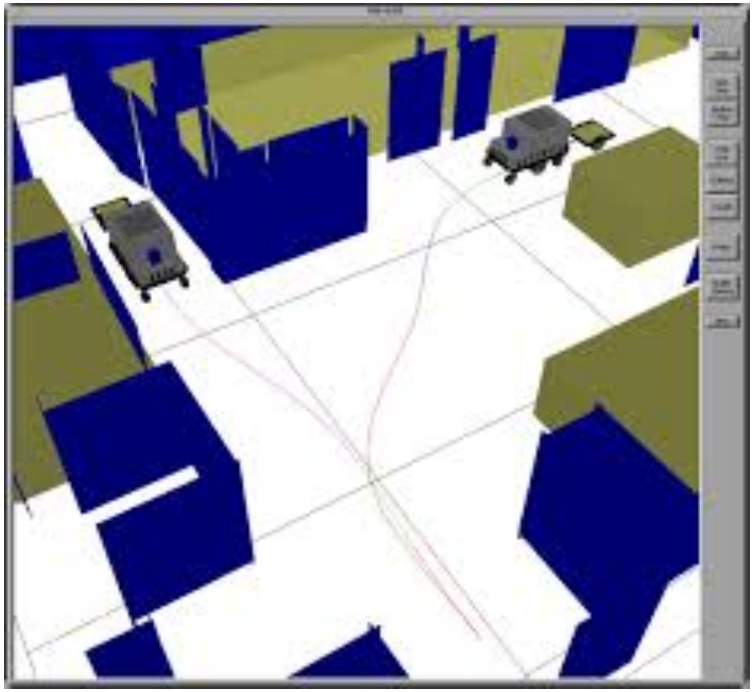
- Find a set of information configurations for individual robots $\{cf(F(e))\}_{e \in \mathcal{E}}$ such that $cf(\{F(e)\}_{e \in \mathcal{E}}) \supseteq cf(F(\mathcal{E}))$

- All except one of these robots can execute a specific MS, which can update v(F(e)) (i.e., the value of F(e))

Definition VI.1 (MS Type)**.** *Given the input IIS s, the type of MS, denoted by $\mathcal{T}(MS(s))$, is an information instance F, such that $v(F)$ is updated by the MS when activated. (If an MS can influence the configuration of more than one information instance, it can be considered as multiple MSs.)* □

Approach

Domain knowledge



- ✧ To identify synergies

Approach

Domain knowledge

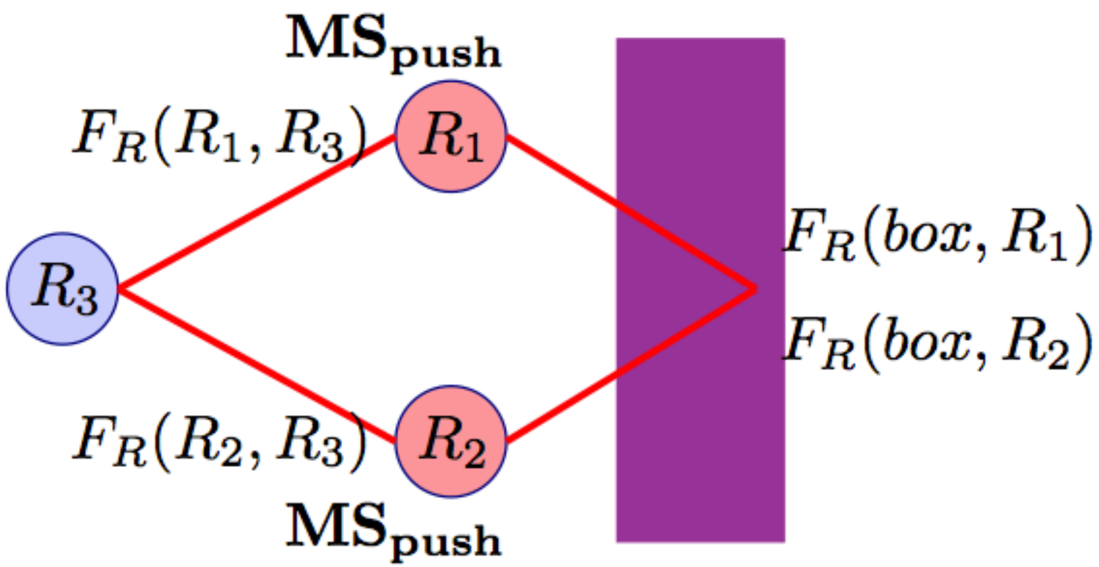
- Domain compatibility,
  E.g., DOM(m(box), MS_{push}({F_G(local), ...})) = F_R(box, local)

- Disjoint configuration
  E.g., orthogonal motion

- Propagated Configuration Constraint
  E.g., cf(F_R(box, R1)) + cf(F_R(box, R2)) -> cf(F_R(R1, R2))

Approach

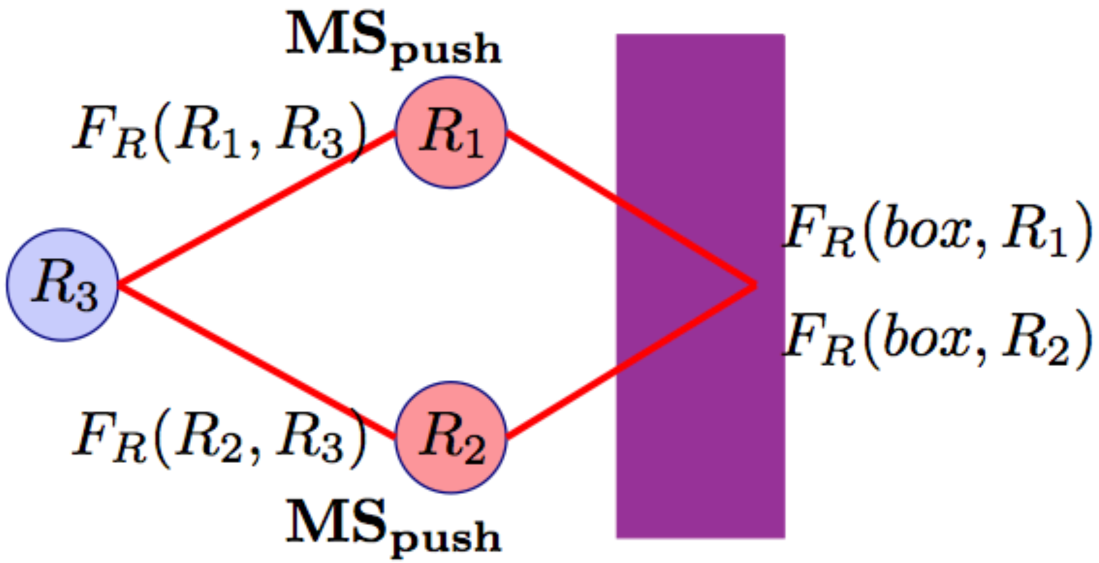
Enable multitasking



Definition VI.2 (Constraint Graph). *Constraint graph is an undirected graph (V, E), in which each node $v \in V$ represents an entity. Two nodes are connected if both are present in the same sensor constraint, and the edge is labeled by the information instance associated with the constraint.* □

Approach

Enable multitasking

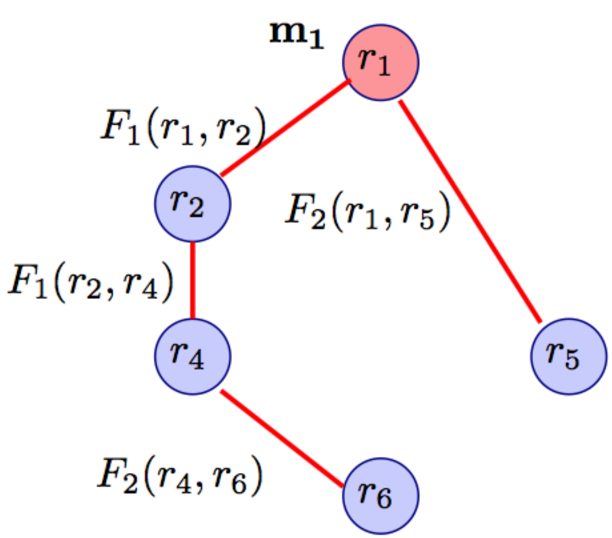


- Identify constraints for individual tasks
- Overlay the constraint graphs
- Search graph for compatible solutions to enable multitasking

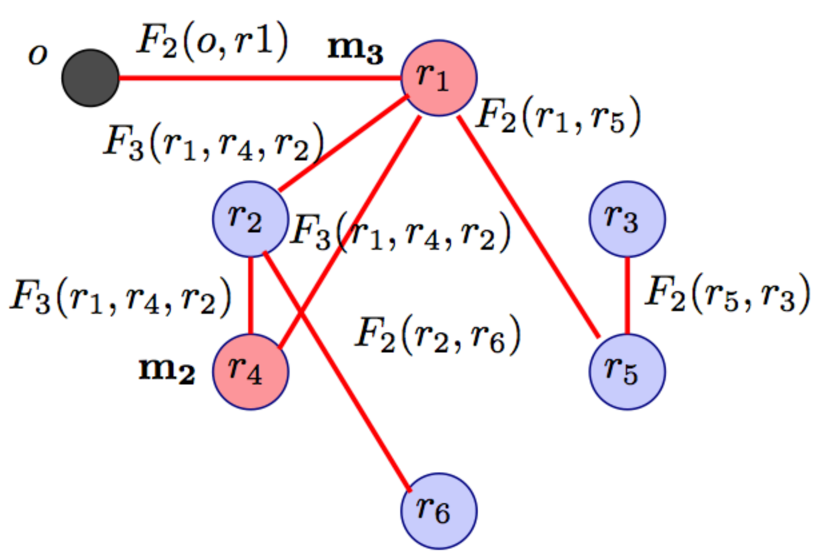
Approach

Enable multitasking

✧ More complex scenarios



1.	$\mathcal{T}(m_2\{F_4(local)\}) = F_4(local)$
2.	$\mathcal{T}(m_3\{F_2(o, local)\}) = F_4(local)$
3.	$DOM(m(o), m_3(\{F_2(o, local)\})) = F_2(o, local)$
4.	$cf(F_4) \cap cf(F_3) \equiv \emptyset$



Approach

Enable multitasking

Algorithm 1 Algorithm for Coalition Coordination

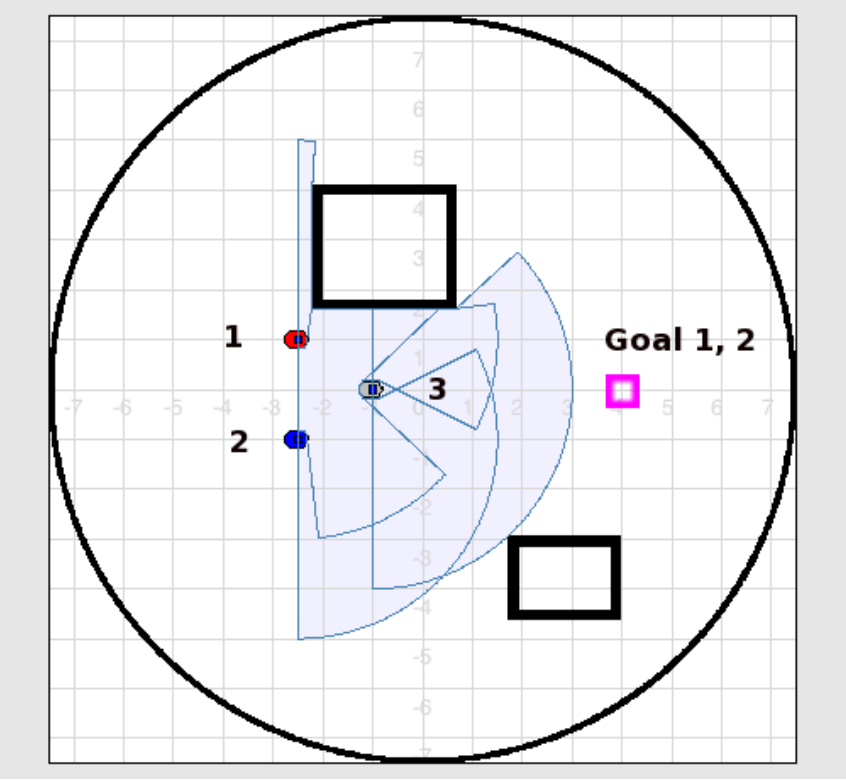
INPUT: a constraint graph $G = (V, E)$; domain compatibilities D; disjoint configurations C.
Create a queue Q and push in all nodes (i.e., robots).
Create a set s for currently satisfied constraints.
Create a set c for checked edges.
Add domain compatibilities to s.
$node$ = POP(Q); Coordinate($node, G, C, D, Q, s, c$).

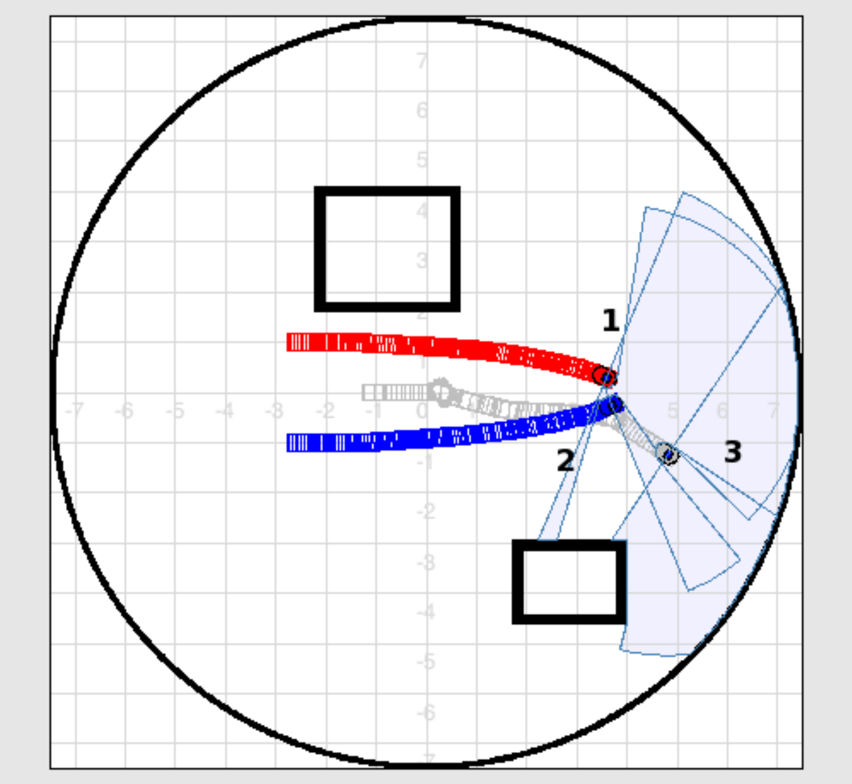
PROCEDURE: Coordinate(v, G, C, D, Q, s, c):
while $(U = \{u : (u, v)_F \in E \ \& \ (u, v)_F \notin c\}) \equiv \emptyset$ **do**
  If $Q \equiv \emptyset$, return solution; else $c = c \cup v$, $v =$ POP(Q).
end while
Add $(u, v)_F \in U$ to c.
if c_1: $cf(F) \not\subseteq cf(s)$ **then**
  for all $x \in \{u, v\}$ **do**
    for all constraint MS m for F on x **do**
      if c_2: $cf(\mathcal{T}(x)) \cap cf(\mathcal{T}(m)) \equiv \emptyset$ or $cf(\mathcal{T}(x)) \equiv \emptyset$ **then**
        $G_x^m =$ Duplicate(G); assign m to x in G_x^m.
        $s_x^m =$ Duplicate(s); add F to s_x^m if the constraint is satisfied.
        Add domain compatibilities to s_x^m.
        $r_x^m =$ Coordinate($v, G_x^m, C, D, Q, s_x^m, c$).
      else
        $r_x^m =$ no solution.
      end if
    end for
  end for
  return $\{r_x^m\}_{m,x}$.
end if
return Coordinate(v, G, C, D, Q, s, c).

✧ Implemented distributedly as DisCSP

Results

Scenario 1

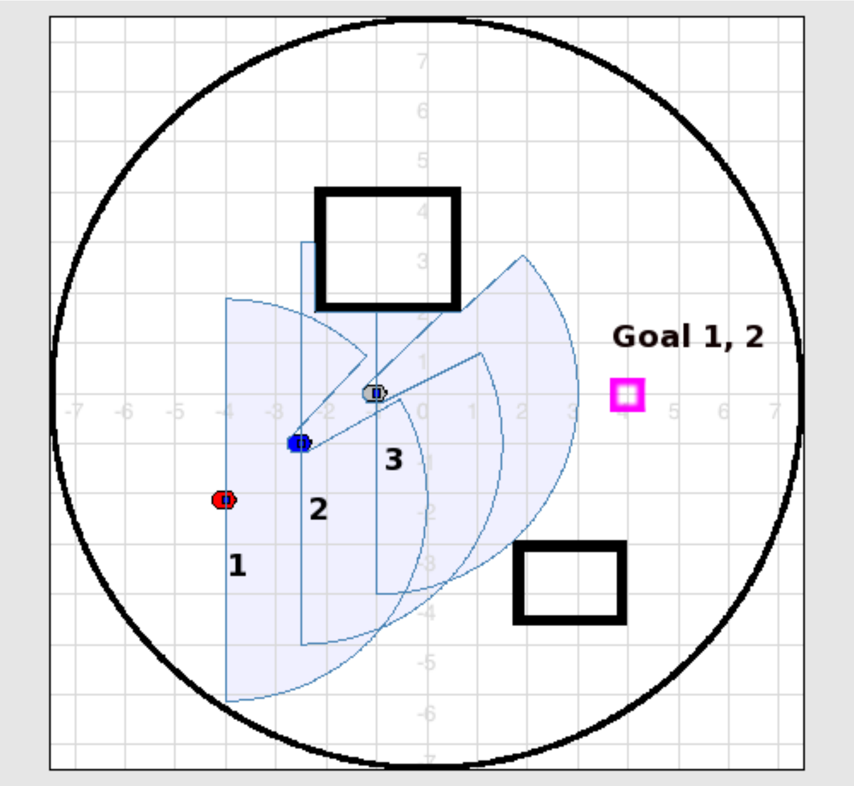


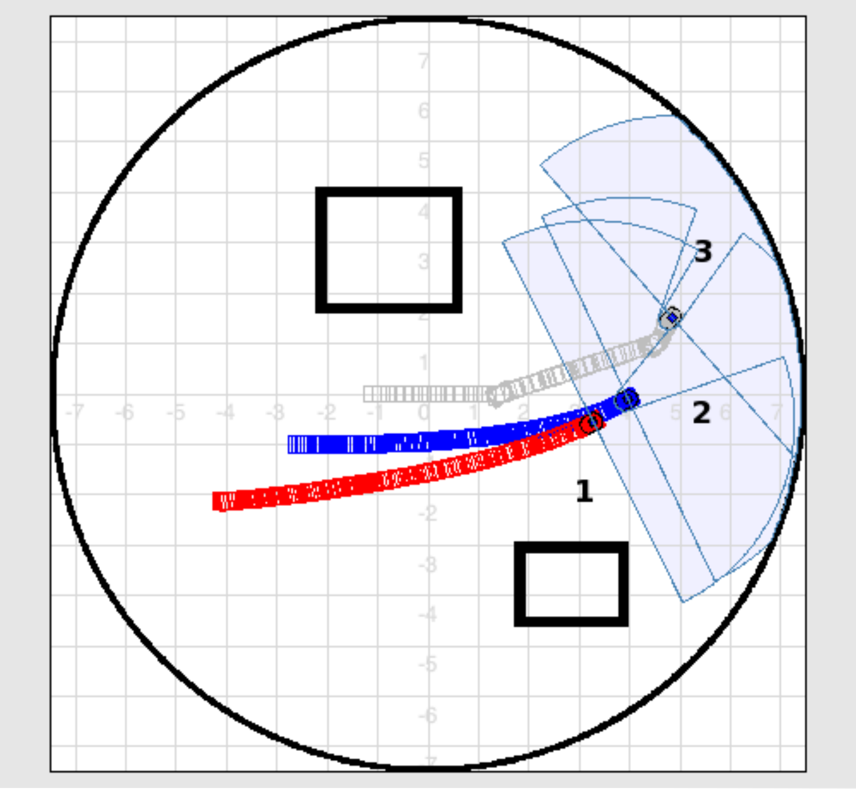


✧ Synergy is utilized to enable multitasking

Results

Scenario 2

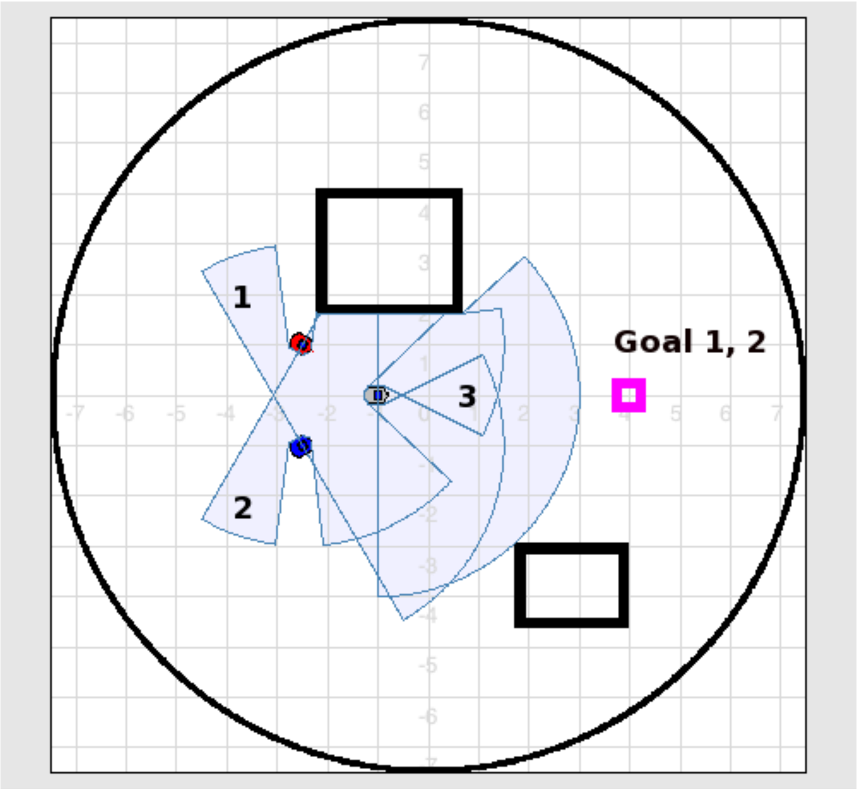


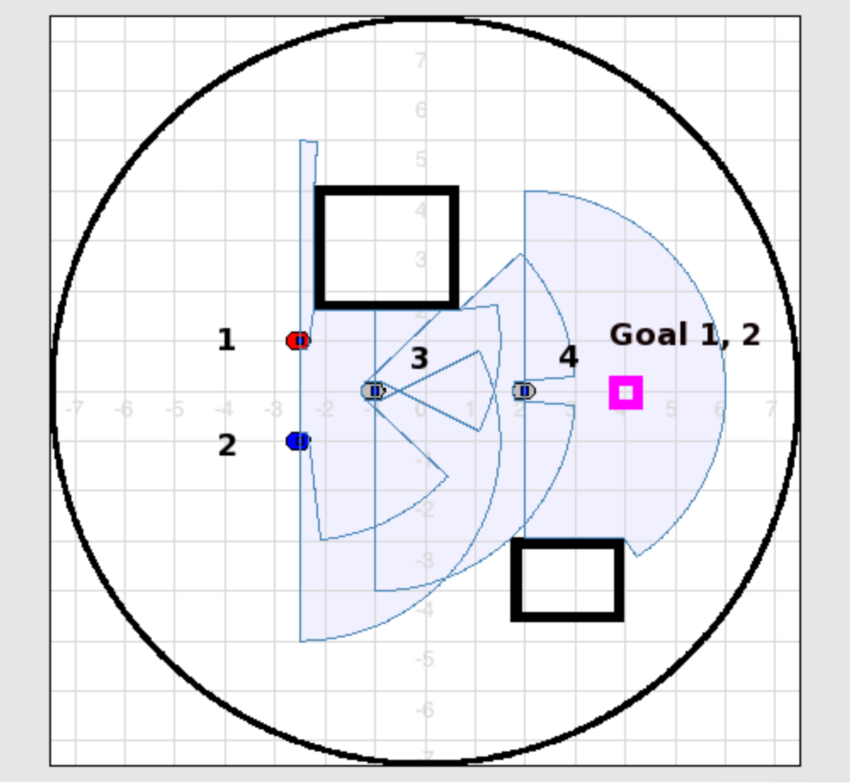


✧ Enable multitasking that is flexible to different configurations

Results

Scenario 3 & 4





- ✧ Identify invalid coalition coordination scenarios

Conclusions

✧ Multitasking in heterogeneous robots:

- Enable coalition execution even when resources are limited
- Automatically identify opportunities for synergies to conserve resources
- Improve task performance

Conclusions

- Proposes a coalition coordination strategy based on sensor constraint for coalition execution in tightly coupled multirobot tasks
- Introduces constraint graph and presents algorithms to search coordination solutions
- Represents the first approach to enabling multi-tasking robots in multirobot tasks (i.e., overlapping coalitions) for improved task performance and resource conservation.