IQ-ASyMTRe: Synthesizing Coalition Formation and Execution for Tightly-Coupled Multirobot Tasks

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About multirobot tasks

<table>
<tr><th>Problem</th><th colspan="3">Solutions</th></tr>
<tr><td rowspan="3">Coalition Formation</td><td colspan="2">Mainly for loosely-coupled</td><td>COBOS [Fua and Ge, 2005]
MR co. form. [Vig and Adams, 2006]</td></tr>
<tr><td rowspan="2">Tightly-coupled
(req. tight coord.)</td><td></td><td>Hoplites [Kalra et al., 2005]</td></tr>
<tr><td>Capability sharing</td><td>ASyMTRe [Parker and Tang, 2006]</td></tr>
<tr><td>Coalition Execution</td><td colspan="3">IQ based approach [Zhang and Parker, 2010] (ICRA)</td></tr>
<tr><td>Formation + Execution</td><td>Previously Unavailable</td><td colspan="2">In this paper: how to Extend ASyMTRe and Combine with IQ?</td></tr>
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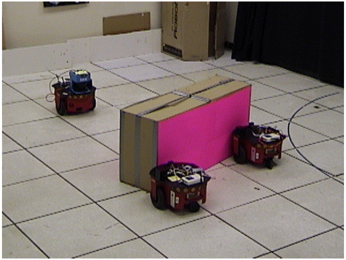
Tightly-coupled multirobot tasks

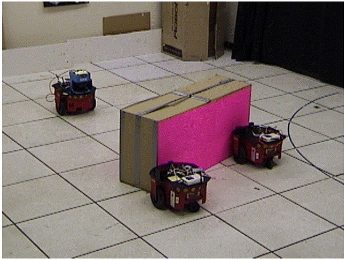
- Heterogeneous robots with different capabilities
- Individual robots incapable of accomplishing the task



(a) [Gerkey and Mataric, 2001]

(b) [Parker and Tang, 2006]

Requirements for achieving the tasks



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Coalition formation:

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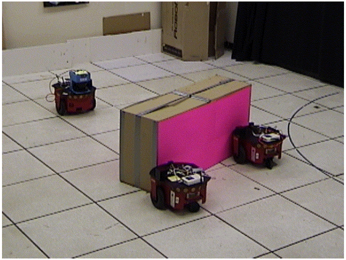

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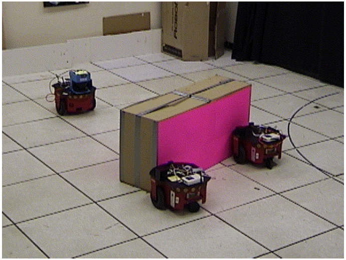
Coalition execution:

- Use the IQ approach to satisfy sensor constraints introduced



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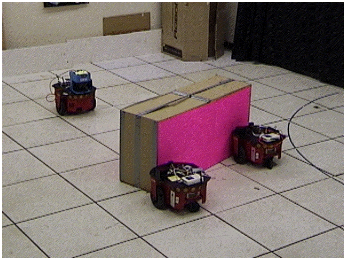

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Coalition formation

ASyMTRe [Parker and Tang, 2006] divides robot capabilities into:

- Motor Schema (MS)
- Environmental Sensor (ES)
- Perceptual Schema (PS)
- Communication Schema (CS)

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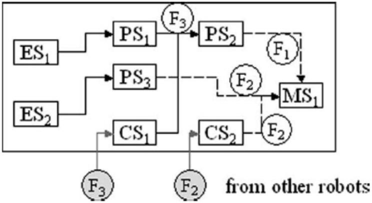

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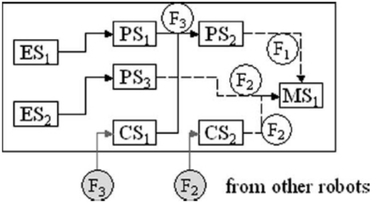

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Capability sharing is implicitly achieved

Requirements for achieving the tasks

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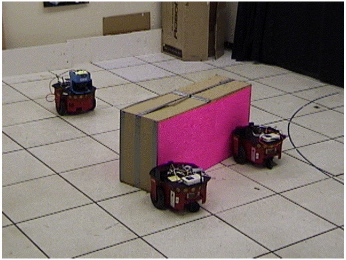

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Coalition execution

An information quality based approach [Zhang and Parker, 2010] (ICRA) for satisfying sensor constraints through:

- Computing the information quality measure based on:
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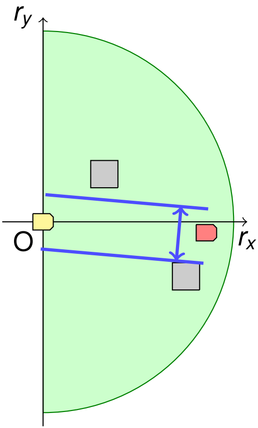

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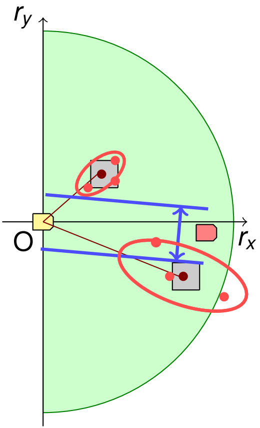
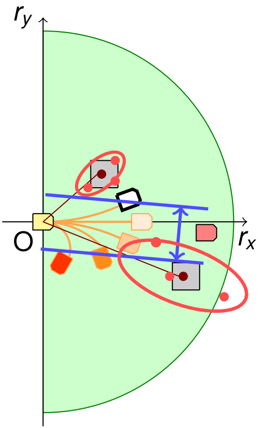


Coalition execution

An information quality based approach [Zhang and Parker, 2010] (ICRA) for satisfying sensor constraints through:

- Computing the information quality measure based on:
  - sensor characteristics
  - environmental influence
- Selecting motion that leads to the best information quality measure



Combining the two approaches

For coalition formation, use ASyMTRe to:

- Search coalition solution

For coalition execution, use the IQ based approach to:

- Maintain sensor constraints

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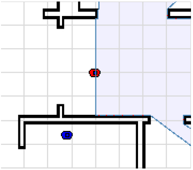
However, $2 = 1 + 1$?

Challenges

Limitations of ASyMTRe for task execution:

(a) Incomplete definition of information type

In the robot navigation task:



(a) Irretrievable information

Challenges

Limitations of ASyMTRe for task execution:

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(b) Application specific design of PSs

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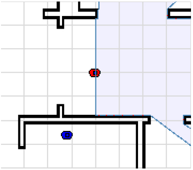

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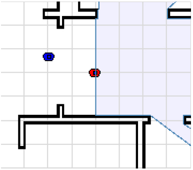

(b) Leader at back

Challenges

Limitations of ASyMTRe for task execution:

(a) Incomplete definition of information type

(b) Application specific design of PSs

(c) Inconsideration of environmental influence

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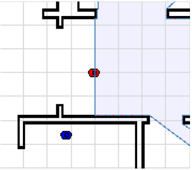

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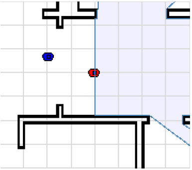

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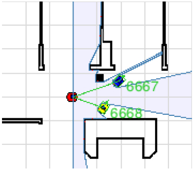

(c) Environmental influence

Contributions

- *Associating referents with information*
  – provides a complete definition of information type

  Guarantees the feasibility of solutions

- *Introducing information conversions*
  – provides more flexibility

  Avoids application specific PS design

- *Combining ASyMTRe and the IQ approach*
  – enables dynamic coalition formation and execution

  Achieves a general solution for tightly-coupled multirobot tasks

A complete definition of information type

$F_i(Ref_{1:N_i})$:

- N_i is the number of referents for F_i
- Ref_j is the jth referent for F_i

For example: $F_G(X)$, $F_G(r_{red})$

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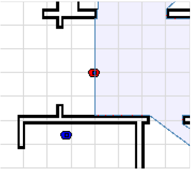

(a) Irretrievable information

$F_R(r_{blue}, r_{red})$ retrievable?

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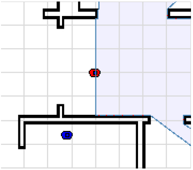
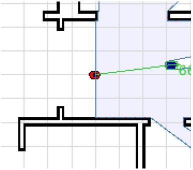


(a) Irretrievable information

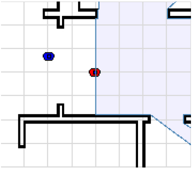
$F_R(r_{blue}, r_{red})$ retrievable? A complete reference of information

Information conversions

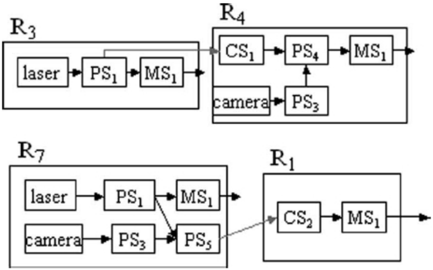
ASyMTRe requires application specific PS design:



(a) Leader at front



(b) Leader at back



(c) [Parker and Tang, 2006]

Information conversions

Table: COMMON INFORMATION CONVERSIONS

$F_G(X) + F_R(Y,X) \rightarrow F_G(Y)$	global + relative → global
$F_R(Y,X) \rightarrow F_R(X,Y)$	relative → relative
$F_R(X,Z) + F_R(Y,Z) \rightarrow F_R(X,Y)$	relative + relative → relative

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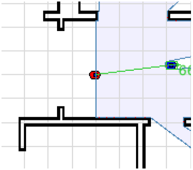

(a) Leader at front

- Leader at front: CS: $F_G(r_{blue})$ + Camera: $F_R(r_{blue}, r_{red})$

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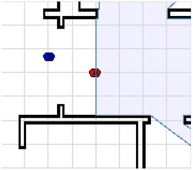

(b) Leader at back

- Leader at back: CS: $F_G(r_{blue})$ + CS: $F_R(r_{red}, r_{blue})$

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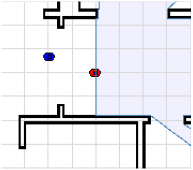
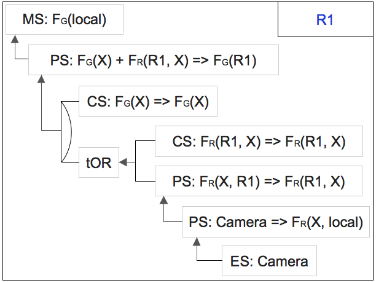


(b) Leader at back

- Leader at back: CS: $F_G(r_{blue})$ + CS: $F_R(r_{red}, r_{blue})$

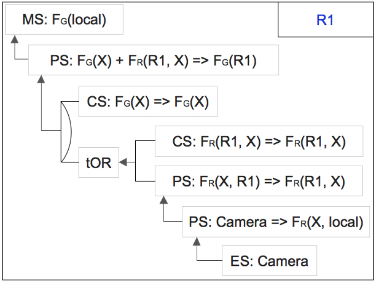
Information conversions provide more flexibility

Solution space and potential solutions



(a) A solution space

Solution space and potential solutions



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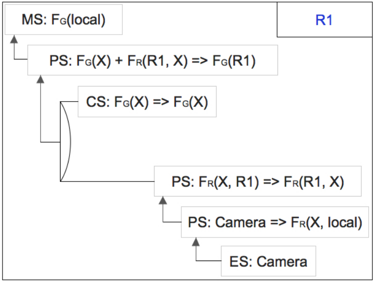
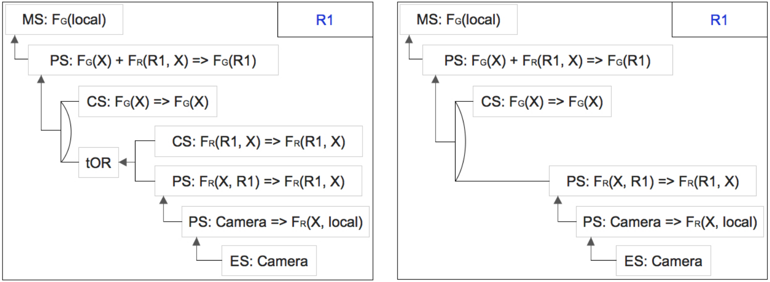


(b) A potential solution in (a)

Solution space and potential solutions



(a) A solution space

(b) A potential solution in (a)

- Additional schema connection constraints are introduced.

IQ for information type

$Q_i(Conf_{1:N_i})$ returns the IQ measure for F_i, given:

- $Conf_{1:N_i}$, configurations for $Ref_{1:N_i}$
- Current environment settings in the sensor's FOV

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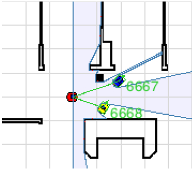

(a) Environmental influence

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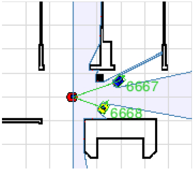

(a) Environmental influence

Enables dynamic-environment reasoning for coalition formation

Algorithm outline

while true **do**
  if a coalition is set up **then**
    if IQ is fairly high **then**
      Execute goal command. – – Coalition execution
    else if IQ is too low **then**
      Break the current coalition.
    else
      Execute the chosen motion to
      increase the IQ. – – Maintain sensor constraints
    end if
  else
    Search for a potential solution.
    Set up a coalition. – – Dynamic coalition Formation
  end if
end while

Challenges - summary

- To provide a complete definition of information type
  – Associate referents with information types
- To avoid application specific design of PSs
  – Introduce information conversions
- To consider environmental influence
  – Incorporate information quality

Simulation – solution space

Table: COMMON INFORMATION CONVERSIONS

$F_G(X) + F_R(Y, X) \rightarrow F_G(Y)$	global + relative → global
$F_R(Y, X) \rightarrow F_R(X, Y)$	relative → relative

Table: ROBOT NAVIGATION TASK

Fiducial Only	Fiducial & Laser
	1. ES:$F_G(local)$
1. CS:$F_G(X)$, ES:$F_R(X, local)$	2. CS:$F_G(X)$, ES:$F_R(X, local)$
2. CS:$F_G(X)$, CS:$F_R(local, X)$	3. CS:$F_G(X)$, CS:$F_R(local, X)$
3. CS:$F_G(X)$, CS:$F_R(X, local)$	4. CS:$F_G(X)$, CS:$F_R(X, local)$
4. CS:$F_G(X)$, CS:$F_R(local, X)$	5. CS:$F_G(X)$, CS:$F_R(local, X)$

Simulation – solution space

Add in: $F_R(X,Z) + F_R(Y,Z) \rightarrow F_R(X,Y)$

Table: ROBOT NAVIGATION TASK

Fiducial & Laser
1. ES:$F_G(local)$
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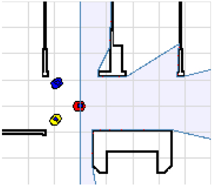
3. CS:$F_G(X)$, CS:$F_R(local, X)$
4. CS:$F_G(X)$, CS:$F_R(X, local)$
5. CS:$F_G(X)$, CS:$F_R(local, X)$
6. CS:$F_G(X)$, CS:$F_R(local, Y)$, CS:$F_R(X, Y)$
7. CS:$F_G(X)$, CS:$F_R(X, Y)$, CS:$F_R(local, Y)$

Simulation – environment reasoning

Environment reasoning ability

Table: NAVIGATION TASK

Fiducial
1. CS:$F_G(X)$, ES:$F_R(X, local)$
2. CS:$F_G(X)$, CS:$F_R(local, X)$
3. CS:$F_G(X)$, CS:$F_R(X, local)$
4. CS:$F_G(X)$, CS:$F_R(local, X)$



(a) No robot in view

$$F_G(X) + F_R(r_{red}, X)$$

Simulation – environment reasoning

Environment reasoning ability

Table: NAVIGATION TASK

Fiducial
1. CS:$F_G(X)$, ES:$F_R(X, local)$
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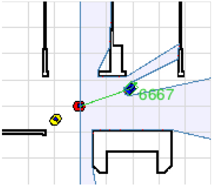

(b) One in view

$F_G(r_{blue})$

Simulation – environment reasoning

Environment reasoning ability

Table: NAVIGATION TASK

Fiducial
1. CS:$F_G(X)$, ES:$F_R(X, local)$
2. CS:$F_G(X)$, CS:$F_R(local, X)$
3. CS:$F_G(X)$, CS:$F_R(X, local)$
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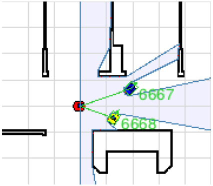

(c) Two in view

$F_G(r_{blue})$ or $F_G(r_{yellow})$

Simulation – environment reasoning

Environment reasoning ability

Table: NAVIGATION TASK

Fiducial
1. CS:$F_G(X)$, ES:$F_R(X, local)$
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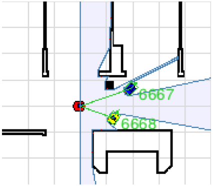
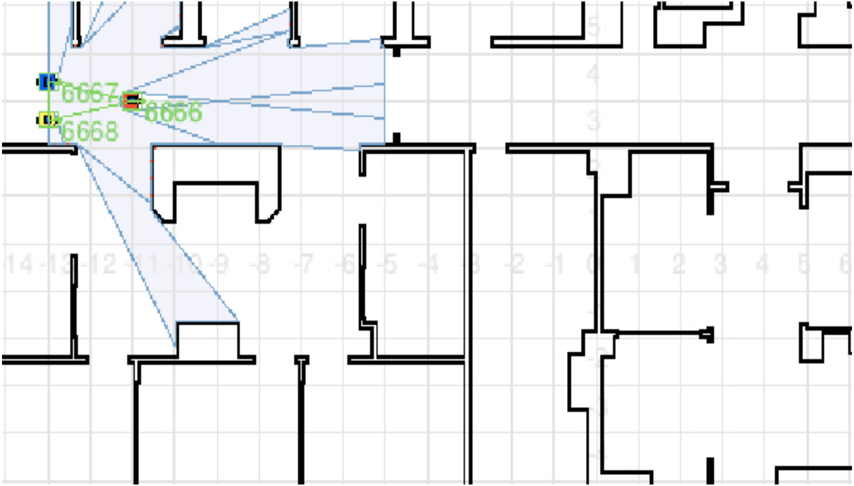


(d) Obstacle in view

$F_G(r_{yellow})$

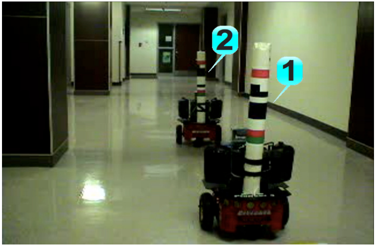
Dynamic coalition formation and execution



Physical experiment – navigation task

Flexibility of information conversions

Leader at front



Leader at back

Contributions

- *Associating referents with information*
  – provides a complete definition of information type

  Guarantees the feasibility of solutions

- *Introducing information conversions*
  – provides more flexibility

  Avoids application specific PS design

- *Combining ASyMTRe and the IQ approach*
  – enables dynamic coalition formation and execution

  Achieves a general solution for tightly-coupled multirobot tasks

References

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