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

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Intelligent Robots and Systems, 2010
### About multirobot tasks

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

Y. Zhang and L.E. Parker

IQ-ASyMTRe for Tightly-Coupled Multirobot Tasks
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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Requirements for achieving the tasks

Coalition formation:

- Use ASyMTRe to **enable capability sharing**

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Coalition formation:
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Coalition execution:
- Use the IQ approach to **satisfy sensor constraints introduced**

(a) [Gerkey and Mataric, 2001]  
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(a) [Gerkey and Mataric, 2001]  
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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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ASyMTRe [Parker and Tang, 2006] divides robot capabilities into:

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

Capability sharing is implicitly achieved

(a) [Parker and Tang, 2006]
Requirements for achieving the tasks

Coalition formation:
- Use ASyMTRe to enable capability sharing

Coalition execution:
- Use the IQ approach to satisfy sensor constraints introduced

(a) [Gerkey and Mataric, 2001]  (b) [Parker and Tang, 2006]
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
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
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
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

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:

(a) Incomplete definition of information type
(b) Application specific design of PSs

In the robot navigation task:

(a) Irretrievable information
(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

In the robot navigation task:

(a) Irretrievable information
(b) Leader at back
(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 \( j \)th referent for \( F_i \)

For example: \( F_G(X) \), \( F_G(r_{red}) \)
A complete definition of information type

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\[ F_R(r_{blue}, r_{red}) \text{ retrievable?} \]
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A complete reference of information
ASyMTRe requires application specific PS design:

(a) Leader at front

(b) Leader at back

c) [Parker and Tang, 2006]
Table: COMMON INFORMATION CONVERSIONS

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Result</th>
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<tr>
<td>$F_G(X) + F_R(Y, X) \rightarrow F_G(Y)$</td>
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Information conversions

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- $F_G(X) + F_R(Y, X) \rightarrow F_G(Y)$
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Leader at front: CS: $F_G(r_{blue}) +$ Camera: $F_R(r_{blue}, r_{red})$
Information conversions

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

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(b) 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

(a) A solution space

(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

\[ Q_i(\text{Conf}_{1:N_i}) \text{ returns the IQ measure for } F_i, \text{ given:} \]

- \( \text{Conf}_{1:N_i} \), configurations for \( \text{Ref}_{1:N_i} \)
- Current environment settings in the sensor’s FOV
IQ for information type

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

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- Current environment settings in the sensor’s FOV

(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
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Table: ROBOT NAVIGATION TASK

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<th>Fiducial Only</th>
<th>Fiducial &amp; Laser</th>
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<td>1. ES: ( F_G(local) )</td>
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<td>4. CS: ( F_G(X) ), CS: ( F_R(local, X) )</td>
<td>5. CS: ( F_G(X) ), CS: ( F_R(local, X) )</td>
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Simulation – solution space

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

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Simulation – environment reasoning

Environment reasoning ability

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$F_G(X) + F_R(r_{red}, X)$
Simulation – environment reasoning

Environment reasoning ability

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\[ F_G(\text{r\_blue}) \]

(b) One in view
Simulation – environment reasoning

Environment reasoning ability

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$F_G(r_{blue})$ or $F_G(r_{yellow})$
Simulation – environment reasoning

Environment reasoning ability

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$F_G(r_{yellow})$

(d) Obstacle in view
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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