Closed Loop Configuration Planning with Time and Resources

M. Di Rocco   F. Pecora   A. Saffiotti

Center for Applied Autonomous Sensor Systems (AASS)
Örebro University, SWEDEN
Configuration... multi robot scenario

Robots run interacting software modules
A simple example
40 mins delay led to 43H trip!
Planning...

Each subsystem can:

- Interact with the environment *(causal constraints)*, e.g. light on

- Take time into consideration *(temporal constraints)*, e.g. deadlines, rendez-vous

- Exploit resources *(resource constraints)*, e.g. a pan-tilt camera, CPU usage

- Exchange information *(information dependencies)*, e.g. motion controller must know position of robot
Closed loop

Most fundamental features:

- Adapting to the state of the environment
- Dynamic goals
- React to contingencies at adequate levels
Architecture

Several solvers reason about the same constraint network

Configuration Solver

Resource Scheduler

State Variable Scheduler

CONSTRAINT NETWORK

CSP BACKTRACKING SEARCH

TEMPORAL FEASIBILITY

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Activities

Activities exchange information, consume resources and require causal requirements.
Configuration process

Activities need requisites about:

• Information

• Environment (EV)

Requisites can be specified through recipes
Operator

HEAD: \((MoveTo\_\text{entrance} \rightarrow \text{kitchen}, ON, \ldots, \ldots, NULL)\)

A:

A1 \((\ldots, \ldots, \ldots, \ldots, Robot.\text{position})\)
A2 \((\ldots, \ldots, \ldots, \ldots, Range\_\text{data})\)
A3 \((Robot.\text{Location}, \text{entrance}, \ldots, \ldots, \ldots)\)
A4 \((Robot.\text{Location}, \text{kitchen}, \ldots, \ldots, \ldots)\)

C:

C1 During
C2 During
C3 After
C4 Before
Conflicts...

- State variable inconsistencies
- Resource overuse

Diagram showing:
- Door state over time with open and closed states.
- CPU usage over time with 100% utilization.
Conflicts...

Amcl

Visual Slam

NAVIGATION

INFORMATION INCONSISTENCIES

INFORMATION INCONSISTENCIES

TEMPORAL INCONSISTENCIES

MoveTo

A->B

B->C

deadline

t
Different solvers...

Backtracking techniques handle conflicts:

- Information Solver
- Resource Scheduler
- State variable scheduler

Constraint Network

Temporal Feasibility
Different solvers...

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CONSTRAINT NETWORK

TEMPORAL FEASIBILITY
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CONSTRAINT NETWORK

TEMPORAL FEASIBILITY
Execution observer – How?

Perception is integrated into the same constraint network

Perception

MoveTo, ON
during
Door_status, OPEN, [0,10][15,25]
equals
Door_sensed, Open...

OPEN
0 3
Execution observer – How?

Perception is integrated into the same constraint network.
Closed-loop architecture

It is possible to describe the plan progress in terms of moves from the goal.
Conflicts at execution time

Conflicts are handled by multiple solvers

GPS → NAVIGATION → AMCL

INFORMATION INCONSISTENCIES
Conflicts at execution time

TEMPORAL INCONSISTENCIES
Robustness...

3 robots must transport goods from Rs to Re. Doors are actuated and rooms have a limited capacity.
Delays

Activities are perturbed by random delays

\[
\text{error } E \quad \text{time}
\]

- \(D_{\text{max}} = 0\)
- \(D_{\text{max}} = 5\)
- \(D_{\text{max}} = 10\)
- \(D_{\text{max}} = 20\)
- \(D_{\text{max}} = 50\)
Resource collapse

Randomly collapse resources are present at plan execution

\[ \text{rigidity (RMS)} \]

\[ \text{time} \]

\[ h_{\text{flex}} \]

\[ h_{\text{rmdm}} \]
Exogenous events

Specifically, at regular intervals $T_{\text{door}}$, each door can be closed with probability $p$

<table>
<thead>
<tr>
<th>$p_{\text{close}}$</th>
<th>0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success rate</td>
<td>1</td>
<td>0.76</td>
<td>0.47</td>
<td>0.3</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Tracking

Rooms are dynamically put under surveillance (two robots must be in the same room to declare a room surveilled)
Two robots inside...
Future work

Which solver to choose depending on the situation (i.e. variable / value ordering heuristics)

Ongoing application in fully integrated robotic systems (Rubicon, Robot-ERA, Race)

Contact: maurizio.di-rocco@aass.oru.se