Extended Capabilities of High-Level Planners

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RACE

SEVENTH FRAMEWORK PROGRAMME

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   - HTN Planner
   - SMACH
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Outline

1 Introduction

2 Basic Concepts
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5 Conclusion

What is planning?

Target

Achieve a desired goal state

- Low-level
    - Motion
    - Path
- High-level

High-level Planner

- Classical
  - Forward chaining
  - Backward chaining
- Temporal
- Probabilistic
  - Markov decision process

Robotic High-level planning

Hierachical Task Network (HTN)

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HTN planner

- SHOP, SHOP2, NONLIN, SIPE-2, O-PLAN, UMCP
- Recursive task decomposition
    - Task size
- Domain specification
    - Operators
    - Methods
    - Axioms
- Problem

HTN Operators

```
(:operator (!name ?arg1 ?arg2)
  (on ?table ?arg1)
  (on ?table ?arg1)
  ((on ?arg2 ?arg1) (:protection (on ?arg2 ?arg1)))
)
```

A sample operator in a SHOP planning domain

HTN Methods

```
(:method (name ?arg1)
   plane
   (enough-cash ?cash)
   ((!buy-ticket ?plane ?x) (!travel ?arg1))
   train
   (not-enough-cash ?cash)
   ((!buy-ticket ?train ?x) (!travel ?arg1))
)
```

A sample method in a SHOP planning domain

HTN Axioms

```
(:- (travel-by-plane ?x)
  (( ticket-price  ?x ?t) (cash-available  ?c) ( call  >= ?c ?t)
    ( distance  ?x ?d) ( call  >= ?d 50)
    ( airport-available ))
)
```

A sample axiom in a SHOP planning domain

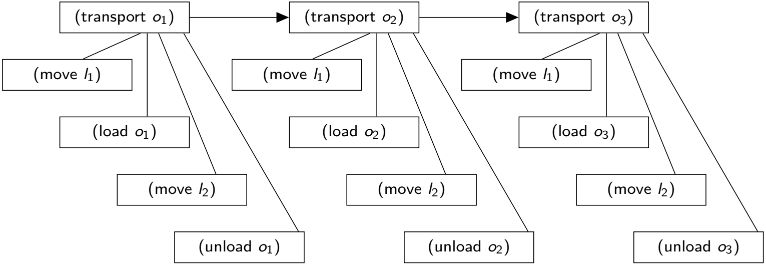
Decomposition

- Structured
- Hierarchical

Decomposition

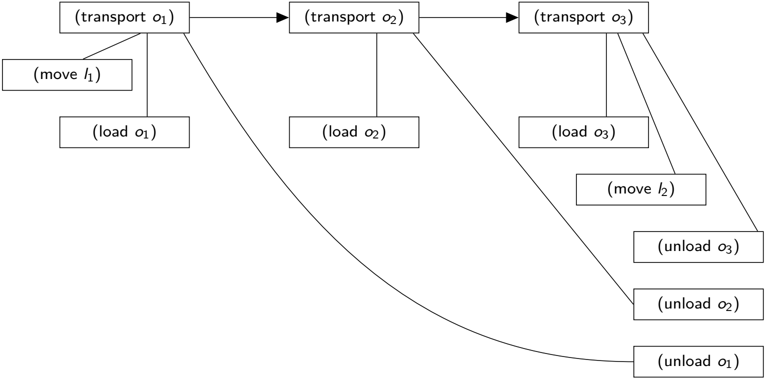
- Structured
- Hierarchical
- SHOP2
  - Partial Order

Partial Ordering



A sample plan for moving three objects generated by SHOP algorithm using total ordering

Partial Ordering



A sample plan using partial ordering

SMACH

- State Machine
  - Native ROS library
  - ROS-independent

SMACH

- State Machine
  - Native ROS library
  - ROS-independent
- States
  - Corresponds to an executable task

SMACH

- State Machine
  - Native ROS library
  - ROS-independent
- States
  - Corresponds to an executable task
- Containers
- Nesting possible

Containers

- State Machine
- Concurrence
- Sequence
- Iterator

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Problem

- Sequential plans
- Resources lie wasted
  - Head
  - Torso
  - Base
  - Right arm
  - Left arm
- Time-inefficient

Operators

- !tuck_arms ?arms
- !move_arm_to_side ?arm
- !move_torso ?position
- !move_base ?to
- !move_base_blind ?to
- !pick_up_object ?object ?arm
- !place_object ?object ?arm ?to

Problem Description

Room contains:

- Robot
- Counter
  - Coffee cup
- Table

Problem Description

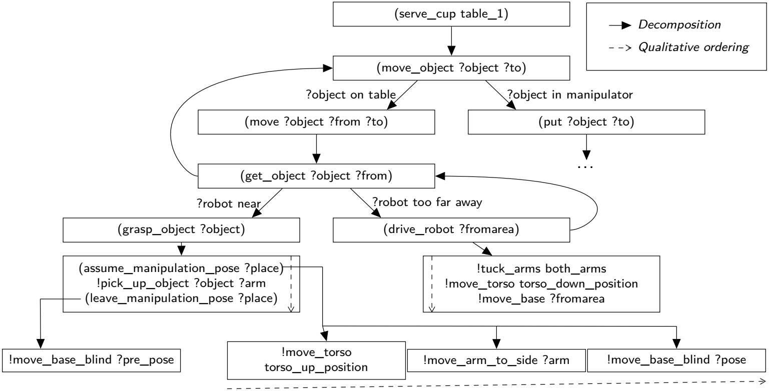
Room contains:

- Robot
- Counter
  - Coffee cup
- Table

Objective

Serve coffee cup

Methods and Decomposition



Domain decomposition for the “Serving Beverages” scenario

Sequential Plan

Analysis

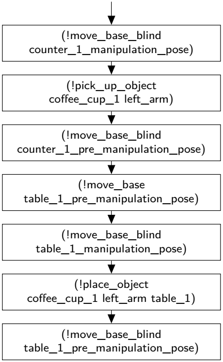
1. *!tuck_arms both_arms*
2. *!move_torso torso_down_position*
3. *!move_base counter_1_pre_manipulation_pose*
4. *!move_torso torso_up_position*
5. *!move_arm_to_side left_arm*
6. *!move_base_blind counter_1_manipulation_pose*
7. *!pick_up_object coffee_cup_1 left_arm*
8. *!move_base_blind counter_1_pre_manipulation_pose*
9. *!move_base table_1_pre_manipulation_pose*
10. *!move_base_blind table_1_manipulation_pose*
11. *!place_object coffee_cup_1 left_arm table_1*
12. *!move_base_blind table_1_pre_manipulation_pose*

Sequential Plan

Analysis

1	*!tuck_arms both_arms*	[RA, LA]
2	*!move_torso torso_down_position*	[T]
3	*!move_base counter_1_pre_manipulation_pose*	[B, RA, LA, T]
4	*!move_torso torso_up_position*	[T]
5	*!move_arm_to_side left_arm*	[LA]
6	*!move_base_blind counter_1_manipulation_pose*	[ALL]
7	*!pick_up_object coffee_cup_1 left_arm*	[LA, H]
8	*!move_base_blind counter_1_pre_manipulation_pose*	[ALL]
9	*!move_base table_1_pre_manipulation_pose*	[B, RA, LA, T]
10	*!move_base_blind table_1_manipulation_pose*	[ALL]
11	*!place_object coffee_cup_1 left_arm table_1*	[LA, H]
12	*!move_base_blind table_1_pre_manipulation_pose*	[ALL]

Parallel Plan – End



(!move_base_blind counter_1_manipulation_pose)

(!pick_up_object coffee_cup_1 left_arm)

(!move_base_blind counter_1_pre_manipulation_pose)

(!move_base table_1_pre_manipulation_pose)

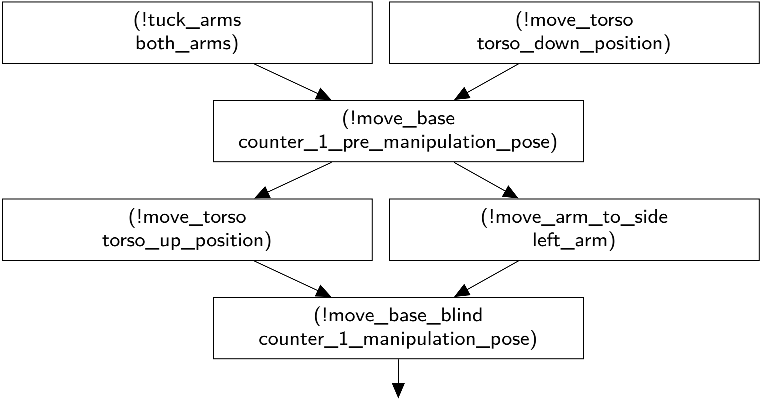
(!move_base_blind table_1_manipulation_pose)

(!place_object coffee_cup_1 left_arm table_1)

(!move_base_blind table_1_pre_manipulation_pose)

Sequential section of the *Serving Beverages* scenario

Parallel Plan – Defensive

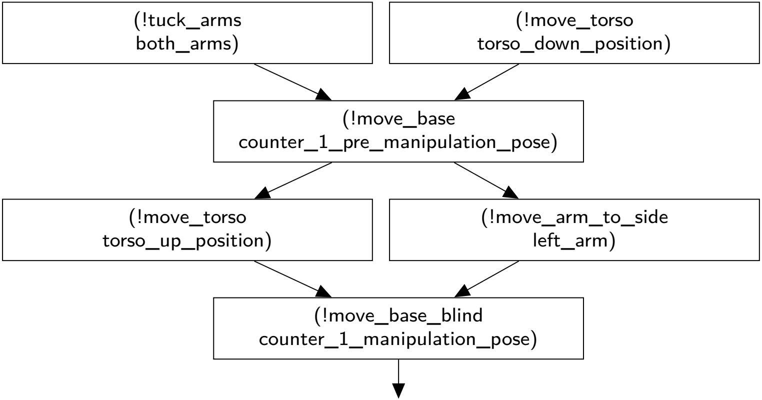

(!tuck_arms both_arms)
(!move_torso torso_down_position)
(!move_base counter_1_pre_manipulation_pose)
(!move_torso torso_up_position)
(!move_arm_to_side left_arm)
(!move_base_blind counter_1_manipulation_pose)

Parallel section of the *Serving Beverages* scenario with security constraint

Implementation

- Linking actions by resources
- Find start actions
- Remove start actions from graph
- Assign actions to *PList* or *SList*
- Loop until graph is empty

Parallel Plan – Defensive



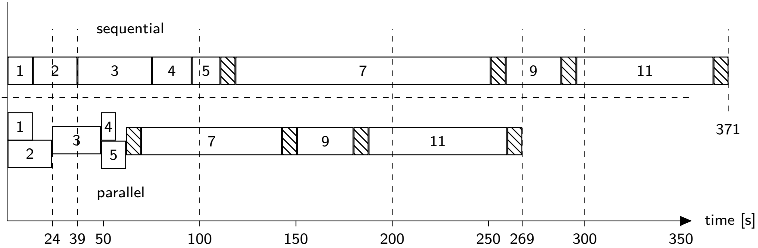
Parallel section of the *Serving Beverages* scenario with security constraint

Soundness

```
(
    [
      —!tuck_arms both_arms—
      —!move_torso torso_down_position—
    ]
  —!move_base counter_1_pre_manipulation_pose—
    (
        [
          —!move_torso torso_up_position—
          —!move_arm_to_side left_arm—
        ]
      —!move_base_blind counter_1_manipulation_pose—
      —!pick_up_object coffee_cup_1 left_arm—
      —!move_base_blind counter_1_pre_manipulation_pose—
      —!move_base table_1_pre_manipulation_pose—
      —!move_base_blind table_1_manipulation_pose—
      —!place_object coffee_cup_1 left_arm table_1—
      —!move_base_blind table_1_pre_manipulation_pose—
    )
)
```

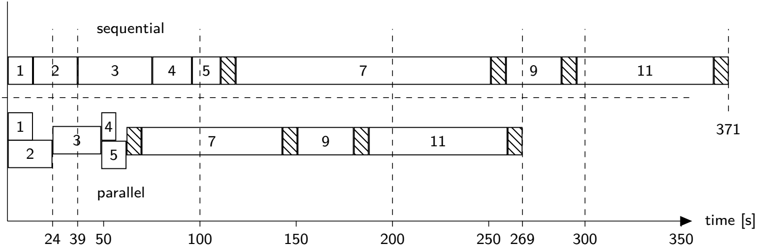
Plan resulting from the parallelization algorithm optimizing the Serving Beverages scenario using security constraints

Practical Experiment - Time



Result from the practical experiment of the Serving Beverages scenario

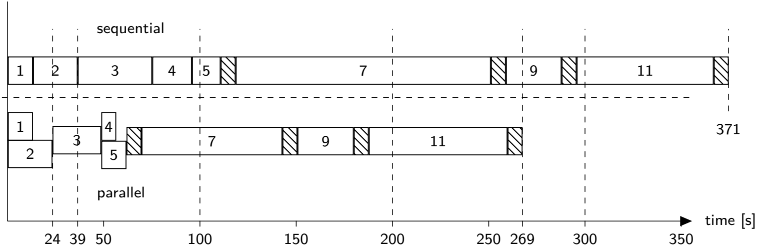
Practical Experiment - Time



Result from the practical experiment of the Serving Beverages scenario

- 102 seconds $\widehat{=}$ 27.5 %

Practical Experiment - Time



Result from the practical experiment of the Serving Beverages scenario

- 102 seconds $\widehat{=}$ 27.5 %
- 15 seconds $\widehat{=}$ 39.5 %

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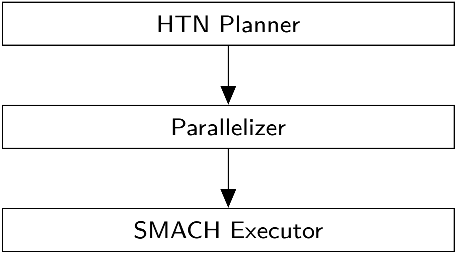
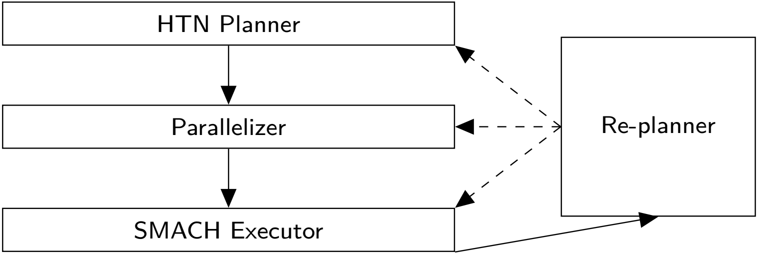
Closed-loop Re-planner



3-Layer parallelization architecture

Closed-loop Re-planner



Closed-loop Re-planning architecture

Cost-success decision

	Cost	Expected Success Rate	Cost-Success
Recognition			
Head	1	1	1
Torso	2	3	$.6\overline{6}$
Base	4	4	1
Grasping			
Head	1	.1	10
Torso	2	2	1
Base	4	8	.5

Cost based vs. cost-success based adaption

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Conclusion

- Introduction to High-level planning
- Challenges
- 3-layered extension for parallel execution
- Closed loop extension for re-planning

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