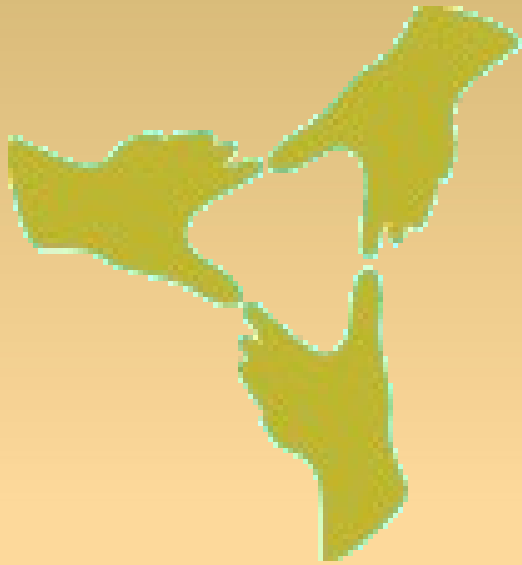


Planning with hybrid knowledge in the GeRT project



GeRT



www.GeRT-Project.eu

F. Lagriffoul, L. Karlsson, F. Pecora and A. Saffiotti

*Center of Applied Autonomous Sensor Systems (AASS)
Örebro university - Sweden*



Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

German Aerospace Center (DLR)



University of Örebro

UNIVERSITY OF
BIRMINGHAM

University of Birmingham



Max-Planck-Institut
für biologische Kybernetik

Max Planck Institute

The GeRT project

Generalizing Robot manipulation Tasks

Aim: coping with novelty in manipulation tasks.

- Abstract away the variability in objects (shape, size and pose)
- Adapt to the context in which the task is performed (obstacles, initial configuration)
- Perform tasks it has not encountered before, given the necessary building blocks for that task

The planning problem in GeRT

Achieving this involves different research areas:

- **Planning**

To compute a sequence of actions to perform the task

- **Learning**

To extract knowledge from example programs

- **Machine perception**

To figure out the locations and types of objects in the scene

- **Grasping**

Which is a difficult problem on its own

The planning problem in GeRT

Achieving this involves different research areas:

- **Planning** → **Hybrid planning**

To compute a sequence of actions to perform the task

Symbolic knowledge

+

Geometric knowledge

- **Learning**

To extract knowledge from example programs

- **Machine perception**

To figure out the locations and types of objects in the scene

- **Grasping**

Which is a difficult problem on its own

The planning problem in GeRT

Hybrid planning

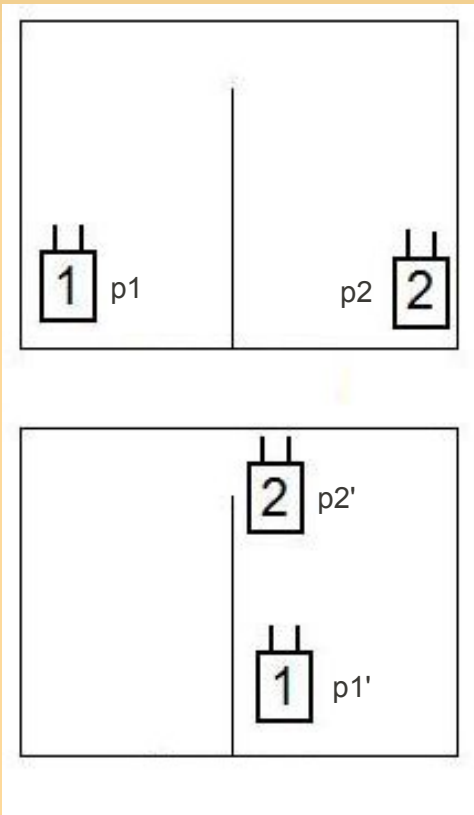
Geometric knowledge

Symbolic knowledge

2 plans are solution to the symbolic problem:

PLAN1:
move robot1 p1'
move robot2 p2'

PLAN2:
move robot2 p2'
move robot1 p1'



Initial state

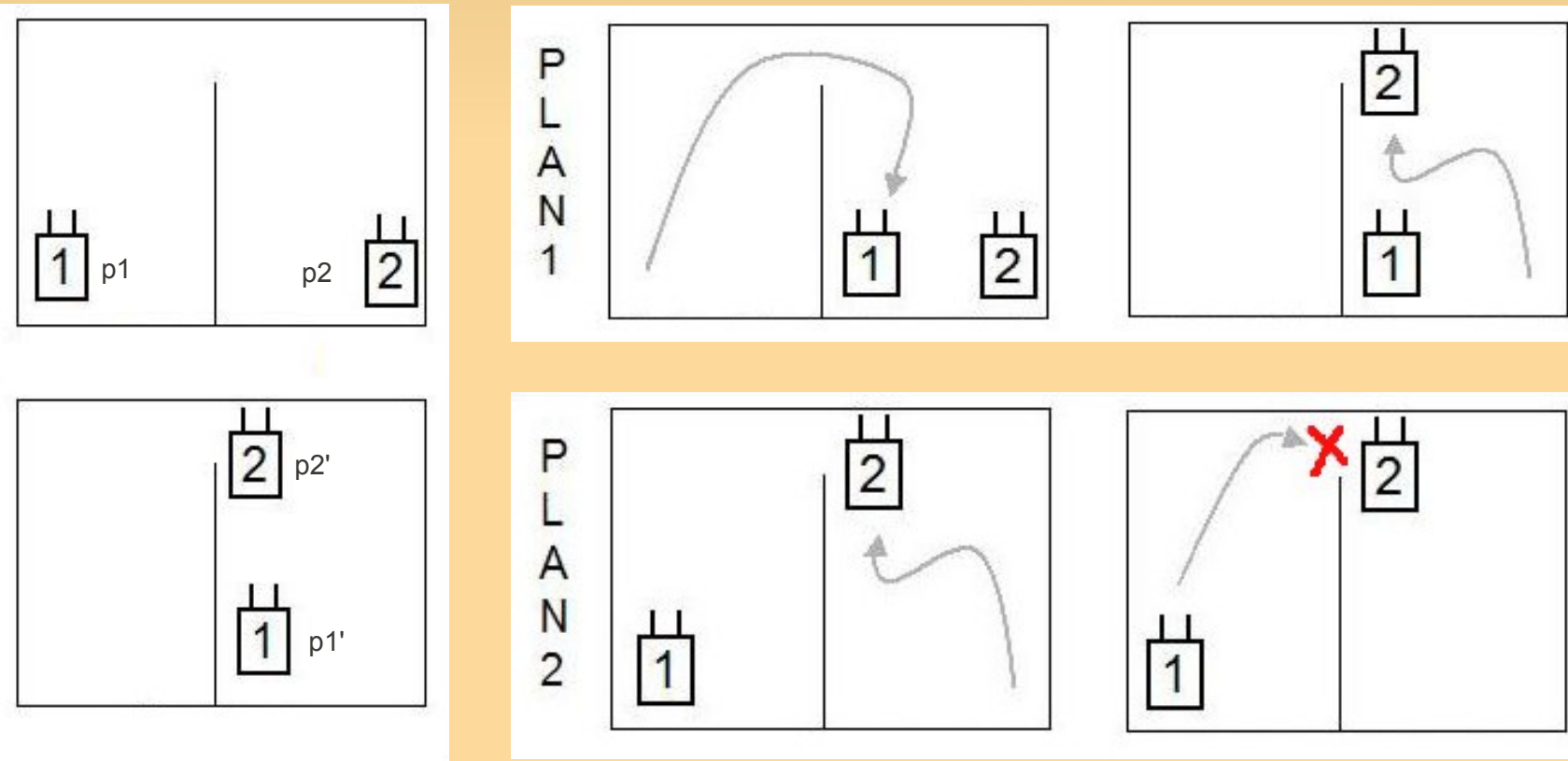
at robot1 p1
at robot2 p2

Goal state

at robot1 p1'
at robot2 p2'

The planning problem in GeRT

Hybrid planning



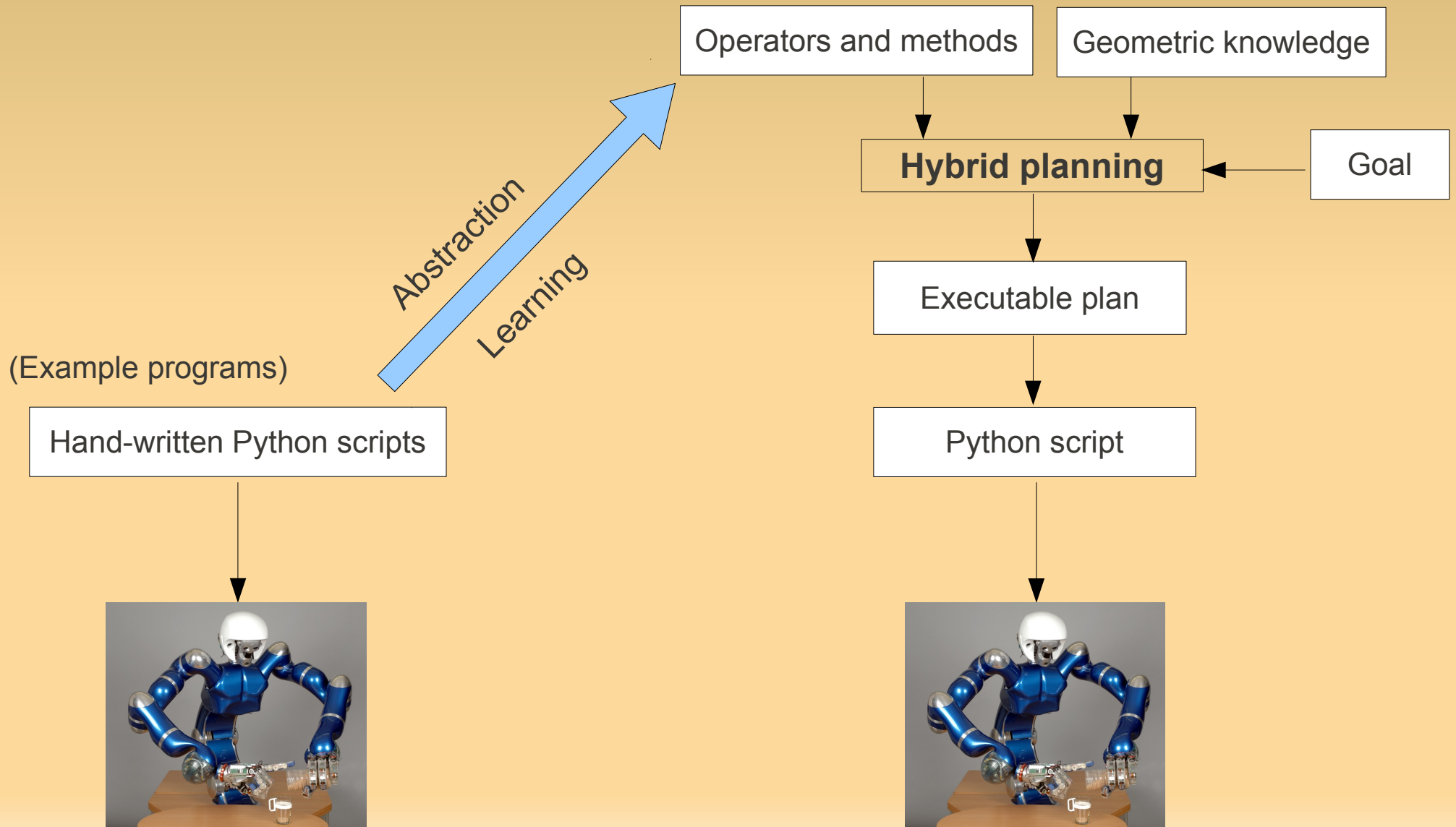
Relation to workshop topics

- **Terminology:** task descriptions, action recipes, skills and other primitives, and what are their relationships?
- **Conventions:** shared definitions, conventions (coordinate systems, units), and data structures
- **Scene graphs:** How should data be represented (maps, objects, actions)? What data should be annotated and how? What kind of reasoning is performed or needed?
- **Reuse of knowledge:** How can a robot decide which knowledge (e.g., map or skill) to reuse in a new situation?
- **Reuse of tools:** What existing software modules, algorithms, libraries, or APIs can be reused?
- **Knowledge engineering:** How will/should the knowledge base grow? What are the processes leading to creation of a substantial knowledge base useful in real applications, i.e. the bootstrapping of the KB?

Terminology, Action recipes

Today:

GeRT:



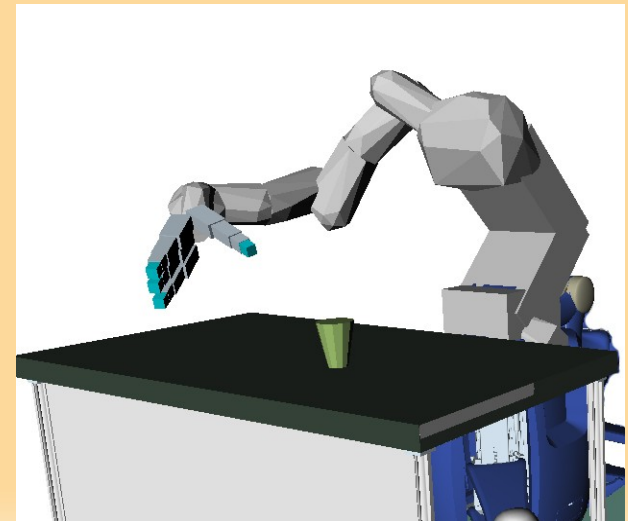
Knowledge representation

■ Symbolic Knowledge

States	Actions
On (Cup1, table) Holding (Teapot, RightHand) Empty (Cup1) ...	<u>Operator</u> : Grab(hand, obj) <u>Preconditions</u> : Free(hand), Clear(obj) <u>Effects</u> : NOT Free(hand), NOT On(obj, table), Holding(hand, obj)

■ Geometric Knowledge

- Geometries of the robot and objects (trimeshes)
- Position and orientation of objects (transformation matrices)
- Configuration of the robot (vector)
- Relative positions (transformation matrices)



Reuse of knowledge: Abstraction

Example programs

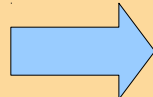
```
4
5 select_cat('cubes')
6 goto_pos(get_ready)
7
8 #open right hand
9 select_cat('common positions')
10 goto 4
11
12 #go
13 select_cat('cubes')
14 goto_pos(get_ready)
15
16 #open right hand
17 select_cat('common positions')
18 goto 4
19
20 #go
21 select_cat('cubes')
22 goto_pos(get_ready)
23
24 #open right hand
25 select_cat('common positions')
26 goto_pos('open right hand')
27
28 #go
29 select_cat('cubes')
30 goto_pos('open right hand')
31
32 #go
33 select_cat('cubes')
34 goto_pos('open right hand')
35
36 #go
37 select_cat('cubes')
38 goto_pos('open right hand')
39
40 #go
41 select_cat('cubes')
42 goto_pos('open right hand')
43
44 #go
45 select_cat('cubes')
46 goto_pos('open right hand')
47
48 #go
49 select_cat('cubes')
50 goto_pos('open right hand')
51
52 #go
53 select_cat('cubes')
54 goto_pos('open right hand')
55
56 #go
57 select_cat('cubes')
58 goto_pos('open right hand')
59
60 #go
61 select_cat('cubes')
62 goto_pos('open right hand')
63
64 #go
65 select_cat('cubes')
66 goto_pos('open right hand')
```

Reuse of knowledge: Abstraction

Example programs

Abstraction / Learning

```
4
5 select_cat('cubes')
6 goto_pos('get ready')
7
8 #open right hand
9 select_cat('common positions')
10 goto 4
11
12 #goto green cube with right hand
13 select_cat('cubes')
14 goto_pos('get ready')
15
16 #open right hand
17 select_cat('common positions')
18 goto 4
19
20 #goto red cube with left hand
21 select_cat('cubes')
22 goto_pos('get ready')
23
24 #open right hand
25 select_cat('common positions')
26 goto_pos('open right hand')
27
28 #goto green cube with right hand
29 select_cat('cubes')
30 goto_pos('right hand pick cup')
31
32 #goto red cube with left hand
33 select_cat('cubes')
34 goto_pos('left hand pick cup')
35
36 #pickup green cube
37 select_cat('common positions')
38 goto_pos('right hand pick cup')
39
40 #dropping right
41 select_cat('cubes')
42 goto_pos('right above drop')
43
44 #right arm away
45 goto_pos('right arm away')
46
47 #pickup red cube
48 select_cat('common positions')
49 goto_pos('left hand pick cup')
50
51 #dropping left
52 select_cat('cubes')
53 goto_pos('left above drop')
54
55 #left arm away
56 goto_pos('left arm away')
57
58 #pickup green cube
59 select_cat('common positions')
60 goto_pos('right hand pick cup')
61
62 #dropping right
63 select_cat('cubes')
64 goto_pos('right above drop')
65
```



```
4
5 select_cat('cubes')
6 goto_pos('get ready')
7
8 #open right hand
9 select_cat('common positions')
10 goto_pos('open right hand')
11
12 #goto green cube with right hand
13 select_cat('cubes')
14 goto_pos('right hand pick cup')
15
16 #open left hand
17 select_cat('common positions')
18 goto_pos('open left hand')
19
20 #goto red cube with left hand
21 select_cat('cubes')
22 goto_pos('left hand pick cup')
23
24 #pickup green cube
25 select_cat('common positions')
26 goto_pos('right hand pick cup')
27
28 #dropping right
29 select_cat('cubes')
30 goto_pos('right above drop')
31
32 #right arm away
33 goto_pos('right arm away')
34
35 #pickup red cube
36 select_cat('common positions')
37 goto_pos('left hand pick cup')
38
39 #dropping left
40 select_cat('cubes')
41 goto_pos('left above drop')
42
43 #left arm away
44 goto_pos('left arm away')
45
46 #pickup green cube
47 select_cat('common positions')
48 goto_pos('right hand pick cup')
49
50 #dropping right
51 select_cat('cubes')
52 goto_pos('right above drop')
53
54 #right arm away
55 goto_pos('right arm away')
56
57 #pickup red cube
58 select_cat('common positions')
59 goto_pos('left hand pick cup')
60
61 #dropping left
62 select_cat('cubes')
63 goto_pos('left above drop')
64
65 #left arm away
66 goto_pos('left arm away')
67
```

```
4
5 select_cat('cubes')
6 goto_pos('get ready')
7
8 #open right hand
9 select_cat('common positions')
10 goto_pos('open right hand')
11
12 #goto green cube with right hand
13 select_cat('cubes')
14 goto_pos('right hand pick cup')
15
16 #open left hand
17 select_cat('common positions')
18 goto_pos('open left hand')
19
20 #goto red cube with left hand
21 select_cat('cubes')
22 goto_pos('left hand pick cup')
23
24 #pickup green cube
25 select_cat('common positions')
26 goto_pos('right hand pick cup')
27
28 #dropping right
29 select_cat('cubes')
30 goto_pos('right above drop')
31
32 #right arm away
33 goto_pos('right arm away')
34
35 #pickup red cube
36 select_cat('common positions')
37 goto_pos('left hand pick cup')
38
39 #dropping left
40 select_cat('cubes')
41 goto_pos('left above drop')
42
43 #left arm away
44 goto_pos('left arm away')
45
46 #pickup green cube
47 select_cat('common positions')
48 goto_pos('right hand pick cup')
49
50 #dropping right
51 select_cat('cubes')
52 goto_pos('right above drop')
53
54 #right arm away
55 goto_pos('right arm away')
56
57 #pickup red cube
58 select_cat('common positions')
59 goto_pos('left hand pick cup')
60
61 #dropping left
62 select_cat('cubes')
63 goto_pos('left above drop')
64
65 #left arm away
66 goto_pos('left arm away')
67
```

Reuse of knowledge: Abstraction

Example programs

```
4 select_cat('cubes')
5 goto_pos('get ready')
6
7
8 #open right hand
9 select_cat('common positions')
10 goto 4
11
12 #go
13 select_cat('cubes')
14 goto_pos('get ready')
15
16 local 8
17 #open right hand
18 select_cat('common positions')
19 goto 4
20
21 #op
22 select_cat('cubes')
23 goto_pos('get ready')
24
25 local 14
26 #open right hand
27 select_cat('common positions')
28 goto_pos('open right hand')
29
30 #go
31 select_cat('cubes')
32 goto_pos('get ready')
33
34 local 18
35 #gato green cube with right hand
36 select_cat('cubes')
37 locate_object('cube_green')
38 goto_frame('right pregrasp green')
39
40 #open left hand
41 select_cat('common positions')
42 goto_pos('open left hand')
43
44 #dr
45 select_cat('cubes')
46 goto_pos('get ready')
47
48 #prip
49 select_cat('cubes')
50 locate_object('cube_green')
51 goto_frame('right above drop')
52
53 #right arm away
54 goto_frame('right arm away')
55
56 #pickup green cube
57 select_cat('common positions')
58 goto_pos('right hand pick cup')
59 app_rave_interface.release('rightArm', 'cube_green')
60
61 #dropping right
62 select_cat('cubes')
63 goto_frame('right above drop')
64 guard.enable('!right_tcp: [[2, '*c', -5.00]])
65 goto_frame('left at drop')
66 guard.disable()
67
68 #frid
69 select_cat('common positions')
70 goto_pos('open right hand')
71 app_rave_interface.release('rightArm', 'cube_green')
72
73 #prip
74 select_cat('cubes')
75 goto_frame('right above drop')
76
77 #right arm away
78 goto_frame('right arm away')
79
80 #pickup red cube
81 select_cat('common positions')
82 goto_pos('open left hand')
83 app_rave_interface.release('leftArm', 'cube_red')
84
85 #dropping left
86 select_cat('cubes')
87 goto_frame('left above drop')
88 guard.enable('!left_tcp: [[2, '*c', -5.00]])
89 goto_frame('left at drop')
90 guard.disable()
91
92 #le
93 select_cat('common positions')
94 goto_pos('open left hand')
95 app_rave_interface.release('leftArm', 'cube_red')
96
97 #left arm away
98 goto_frame('left arm away')
```

Abstraction / Learning

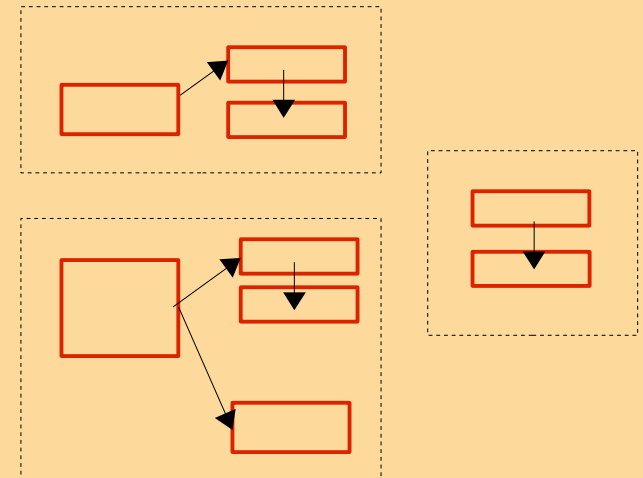
```
4 select_cat('cubes')
5 goto_pos('get ready')
6
7
8 #open right hand
9 select_cat('common positions')
10 goto_pos('open right hand')
11
12 #gato green cube with right hand
13 locate_object('cube_green')
14 goto_frame('right pregrasp green')
15
16 #open left hand
17 select_cat('common positions')
18 goto_pos('open left hand')
19
20 #go
21 select_cat('cubes')
22 goto_pos('get ready')
23
24 #gato red cube with left hand
25 locate_object('cube_red')
26 goto_frame('left pregrasp red')
27
28 #dropping right
29 select_cat('cubes')
30 goto_frame('right above drop')
31 guard.enable('!right_tcp: [[2, '*c', -5.00]])
32 goto_frame('left at drop')
33 guard.disable()
34
35 #prip
36 select_cat('cubes')
37 locate_object('cube_green')
38 goto_frame('right above drop')
39
40 #right arm away
41 goto_frame('right arm away')
42
43 #pickup red cube
44 select_cat('common positions')
45 goto_pos('right hand pick cup')
46 app_rave_interface.release('rightArm', 'cube_red')
47
48 #dropping left
49 select_cat('cubes')
50 goto_frame('left above drop')
51 guard.enable('!left_tcp: [[2, '*c', -5.00]])
52 goto_frame('left at drop')
53 guard.disable()
54
55 #le
56 select_cat('common positions')
57 goto_pos('open left hand')
58 app_rave_interface.release('leftArm', 'cube_red')
59
60 #left arm away
61 goto_frame('left arm away')
```

```
4 select_cat('cubes')
5 goto_pos('get ready')
6
7
8 #open right hand
9 select_cat('common positions')
10 goto_pos('open right hand')
11
12 #gato green cube with right hand
13 locate_object('cube_green')
14 goto_frame('right pregrasp green')
15
16 #open left hand
17 select_cat('common positions')
18 goto_pos('open left hand')
19
20 #go
21 select_cat('cubes')
22 goto_pos('get ready')
23
24 #gato red cube with left hand
25 locate_object('cube_red')
26 goto_frame('left pregrasp red')
27
28 #dropping right
29 select_cat('cubes')
30 goto_frame('right above drop')
31 guard.enable('!right_tcp: [[2, '*c', -5.00]])
32 goto_frame('left at drop')
33 guard.disable()
34
35 #prip
36 select_cat('cubes')
37 locate_object('cube_green')
38 goto_frame('right above drop')
39
40 #right arm away
41 goto_frame('right arm away')
42
43 #pickup red cube
44 select_cat('common positions')
45 goto_pos('right hand pick cup')
46 app_rave_interface.release('rightArm', 'cube_red')
47
48 #dropping left
49 select_cat('cubes')
50 goto_frame('left above drop')
51 guard.enable('!left_tcp: [[2, '*c', -5.00]])
52 goto_frame('left at drop')
53 guard.disable()
54
55 #le
56 select_cat('common positions')
57 goto_pos('open left hand')
58 app_rave_interface.release('leftArm', 'cube_red')
59
60 #left arm away
61 goto_frame('left arm away')
```

Operators

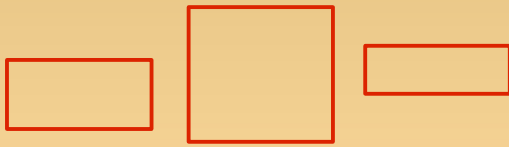


Methods

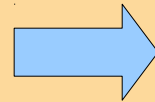
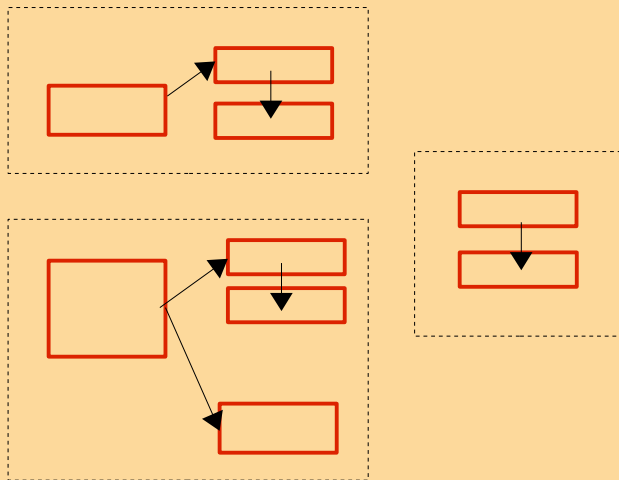


Reuse of knowledge: solving a new task

Operators



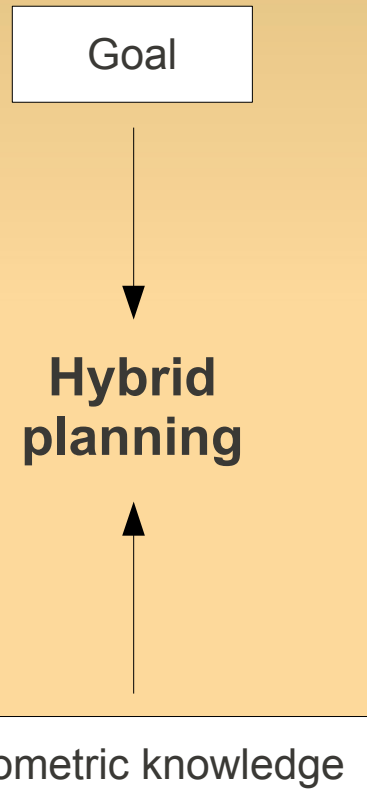
Methods



Goal

Hybrid
planning

Geometric knowledge

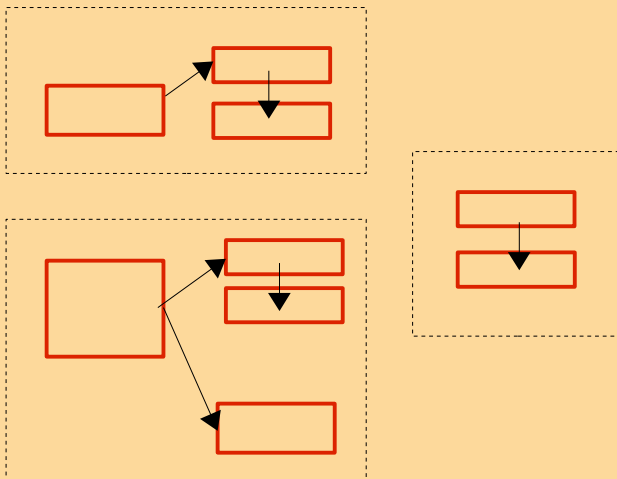


Reuse of knowledge: solving a new task

Operators



Methods



Goal

Hybrid
planning

Geometric knowledge

Python script

```
4
5 select_cat('cubes')
6 goto_pos('get ready')
7
8 #open right hand
9 select_cat('common positions')
10 goto_pos('open right hand')
11
12 #goto green cube with right hand
13 select_cat('cubes')
14 locate_object('cube_green')
15 goto_frame('right pregrasp green')
16
17 #open left hand
18 select_cat('common positions')
19 goto_pos('open left hand')
20
21 #goto red cube with left hand
22 select_cat('cubes')
23 locate_object('cube_red')
24 goto_frame('left pregrasp red')
25
26 #pickup green cube
27 select_cat('common positions')
28 goto_pos('right hand pick cup')
29 app.rave_interface.bind('rightArm', 'cube_green')
30
31 #dropping right
32 select_cat('cubes')
33 goto_frame('right above drop')
34 guard.enable({'right_tcp': [(2, '<', -5.00)]})
35 goto_frame('right at drop')
36 guard.disable()
37 select_cat('common positions')
38 goto_pos('open right hand')
39 app.rave_interface.release('rightArm', 'cube_green')
40 select_cat('cubes')
41 goto_frame('right above drop')
42
43 #right arm away
44 goto_frame('right arm away')
45
46 #pickup red cube
47 select_cat('common positions')
48 goto_pos('left hand pick cup')
49 app.rave_interface.bind('leftArm', 'cube_red')
50
51 #dropping left
52 select_cat('cubes')
53 goto_frame('left above drop')
54 guard.enable({'left_tcp': [(2, '<', -5.00)]})
55 goto_frame('left at drop')
56 guard.disable()
57 select_cat('common positions')
58 goto_pos('open left hand')
59 app.rave_interface.release('leftArm', 'cube_red')
60 select_cat('cubes')
61 goto_frame('left above drop')
62
63 #left arm away
64 goto_frame('left arm away')
65
```

The End

Thanks for your attention.

Questions?