An Admissible HTN Planning Heuristic

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- How to solve these problems based on well-informed domain-independent heuristics?
- How to provide optimality guarantees?

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We base our formalization upon *hybrid planning*, which fuses

- hierarchical task network (HTN) planning with
- partial order causal link (POCL) planning.

Related Work:

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- HTN planners using control knowledge (e.g., SHOP2).

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- Hierarchical heuristic search planners for different problem classes (e.g., hybrid, HGN, GTN, HTN+preferences).

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- a planning domain stating the tasks (primitive and abstract) and methods (how to refine an abstract action?), and
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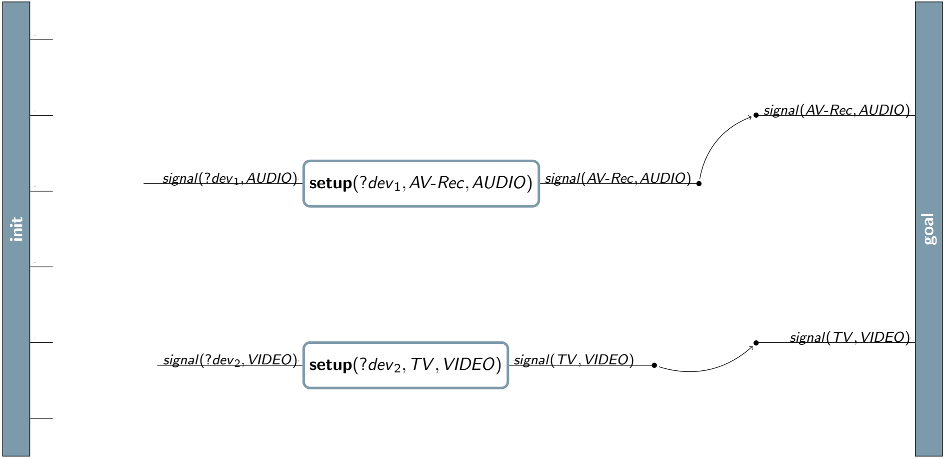
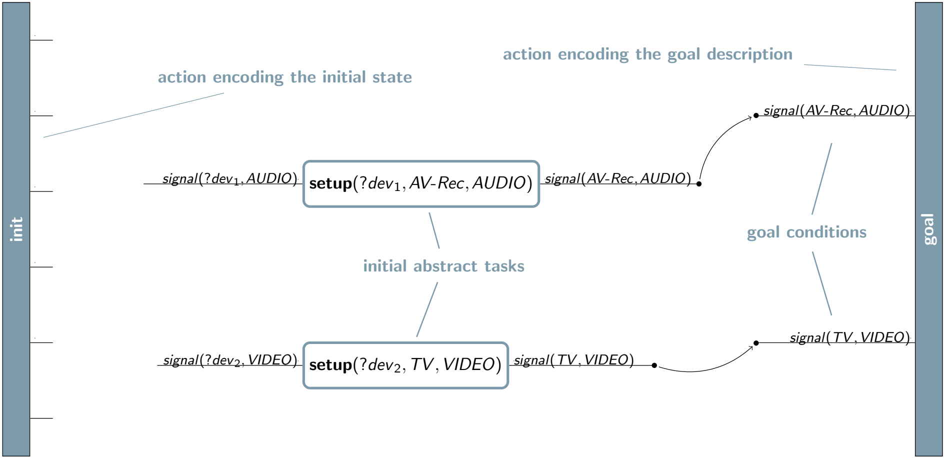
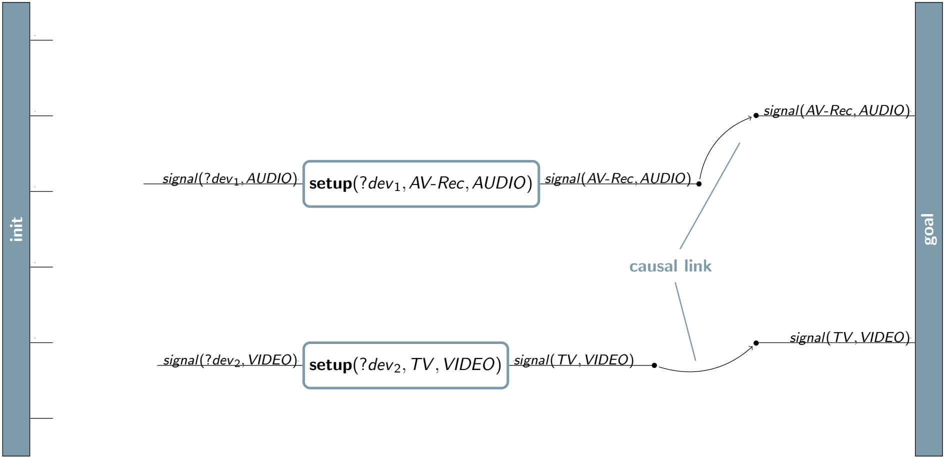
A solution is a partially ordered plan, such that:

- it is a primitive refinement of the initial partial plan,
- all its linearizationd are executable in the initial state, and
- all its linearization satisfy the goal description.

$\rightsquigarrow$ *see example given next.*


init
signal(?dev1, AUDIO)
setup(?dev1, AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(?dev2, VIDEO)
setup(?dev2, TV, VIDEO)
signal(TV, VIDEO)
signal(TV, VIDEO)
goal


action encoding the initial state
action encoding the goal description
init
goal
signal(?dev1, AUDIO)
setup(?dev1, AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
goal conditions
initial abstract tasks
signal(TV, VIDEO)
signal(?dev2, VIDEO)
setup(?dev2, TV, VIDEO)
signal(TV, VIDEO)


init
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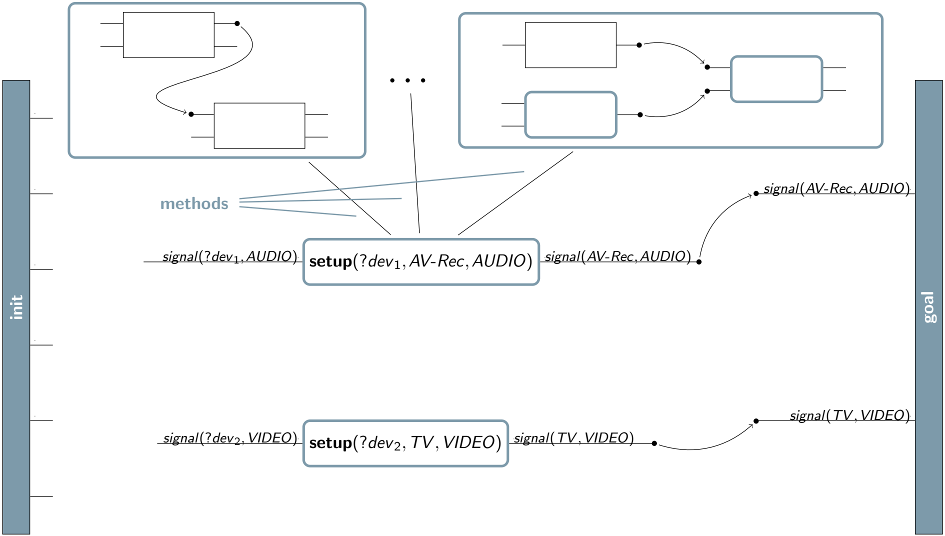
setup(?dev1, AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(?dev2, VIDEO)
setup(?dev2, TV, VIDEO)
signal(TV, VIDEO)
causal link
signal(AV-Rec, AUDIO)
signal(TV, VIDEO)
goal


methods
init
goal
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setup(?dev1, AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(AV-Rec, AUDIO)
signal(?dev2, VIDEO)
setup(?dev2, TV, VIDEO)
signal(TV, VIDEO)
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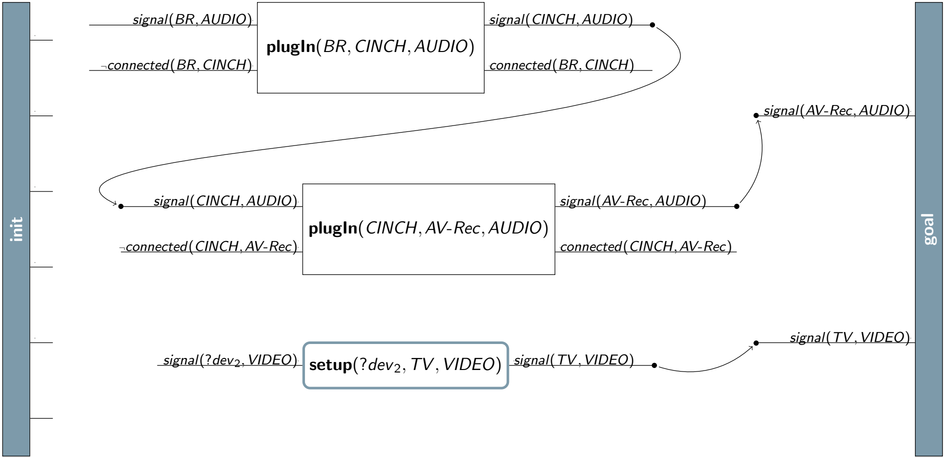
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plugIn(BR, CINCH, AUDIO)
signal(CINCH, AUDIO)
connected(BR, CINCH)
signal(AV-Rec, AUDIO)
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signal(TV, VIDEO)
signal(?dev2, VIDEO)
setup(?dev2, TV, VIDEO)
signal(TV, VIDEO)
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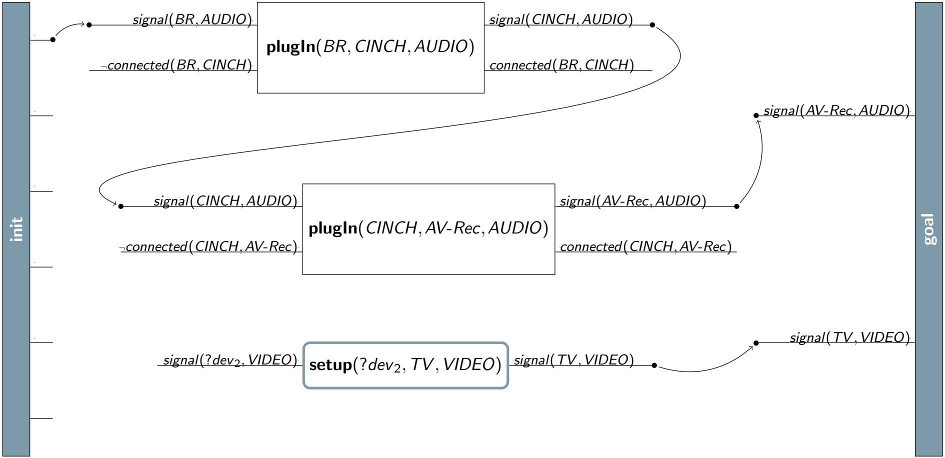

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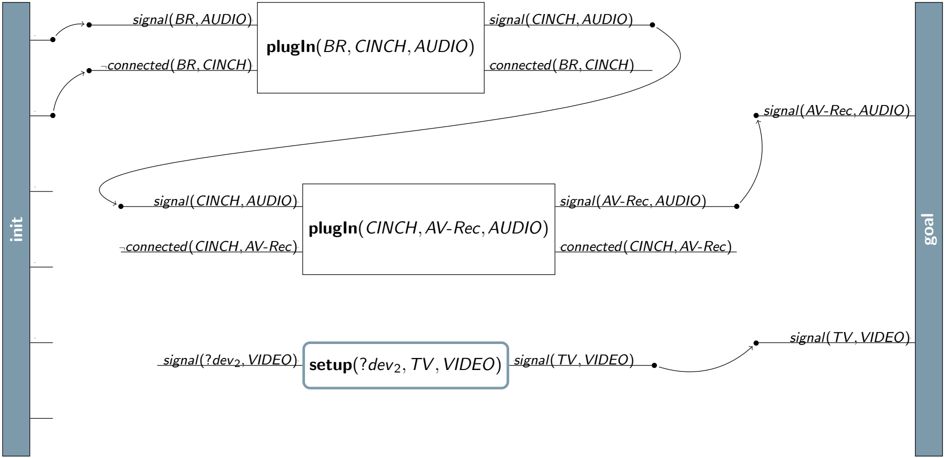
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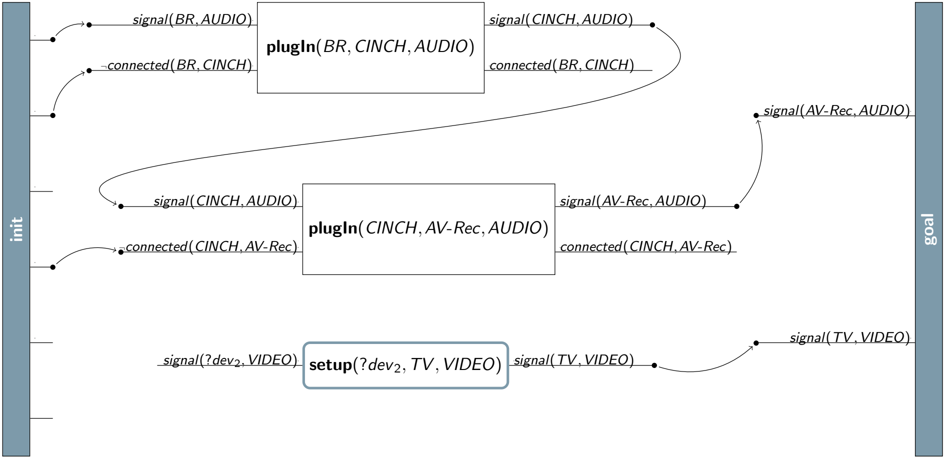
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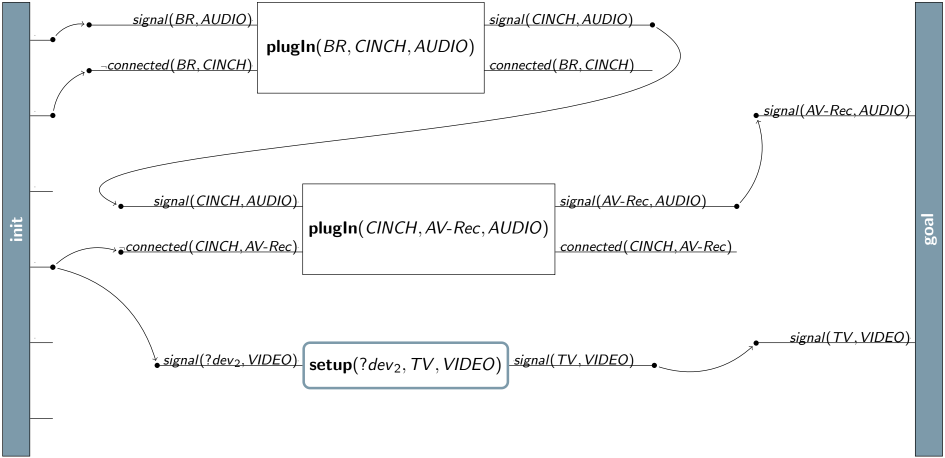
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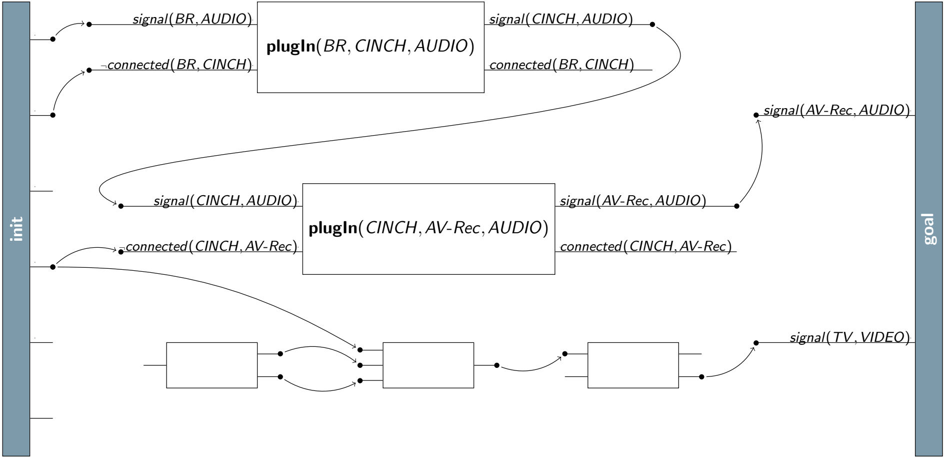
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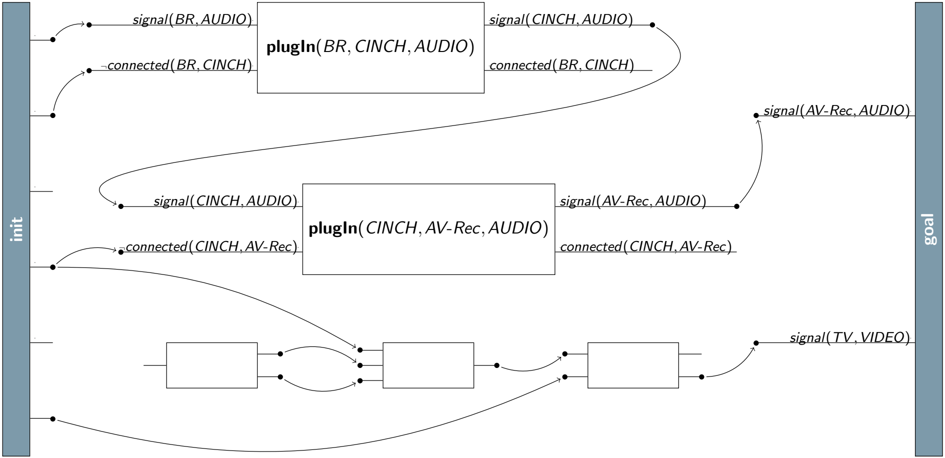
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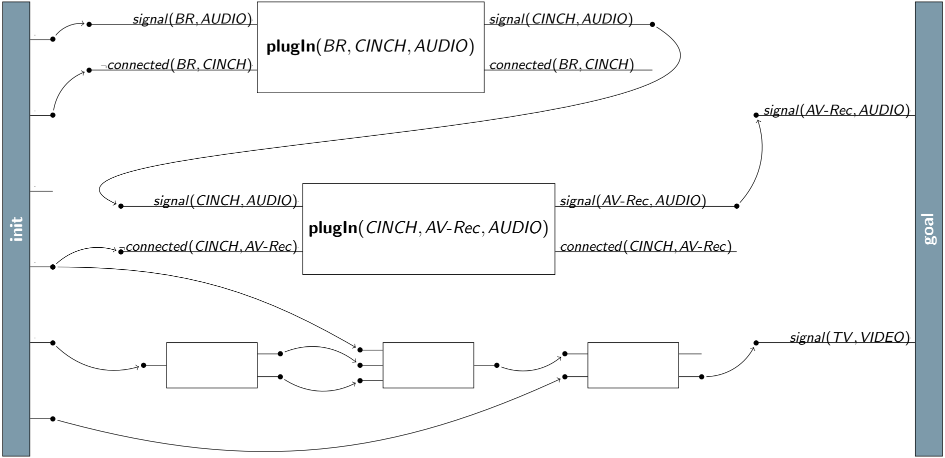
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How to come up with heuristic functions?

- Both HTN and hybrid problems are *undecidable*, we hence need severe problem relaxations that them *decidable* and *tractable*.
- ⇝ We allow task insertion.
- ⇝ We make the problem acyclic.

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How does the heuristic work?

Step 1:

- Build a so-called task-decomposition graph (TDG), which represents the hierarchical problem structure.

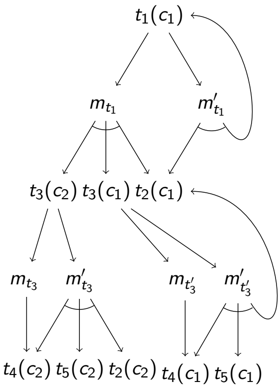
Step 2:

- Calculate heuristic estimates for all tasks in that TDG.

Step 3:

- For a given plan, retrieve the TDG's estimates for all abstract tasks in that plan.

Task decomposition Graph (TDG), example:



A TDG is a ground representation of the task hierarchy.

It is a (possibly cyclic) bipartite graph $\langle V_T, V_M, E_{T\to M}, E_{M\to T}\rangle$ consisting of:

- task vertices V_T (abstract task vertices are OR nodes)
- method vertices V_M (which are AND nods)

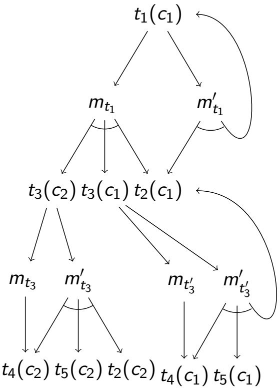
Let $\langle V_T, V_M, E_{T\to M}, E_{M\to T}\rangle$ be a ground TDG. Then, we can calculate a heuristics by exploiting its AND/OR structure:

$$h_T(v_t) := \begin{cases} cost(v_t) & \text{if } v_t \text{ is primitive} \\ \min_{(v_t,v_m)\in E_{T\to M}} h_M(v_m) & \text{else} \end{cases}$$

For a method vertex $v_m = \langle PS, \prec, CL, VC\rangle$, we set:

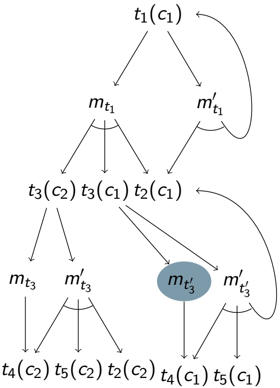
$$h_M(v_m) := \sum_{(v_m,v_t)\in E_{M\to T}} h_T(v_t)$$

Heuristic computation, example:



$$h(m'_{t_3}) = cost(t_4(c_1))$$
$$h(m'_{t'_3}) = cost(t_4(c_1)) + cost(t_5(c_1)) + cost(t_2(c_1))$$
$$h(t_3(c_1)) = min\{h(m'_{t_3}), h(m'_{t'_3})\}$$
$$\dots$$

Heuristic computation, example:



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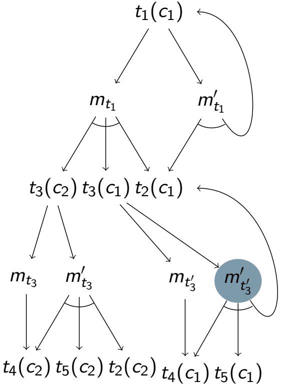

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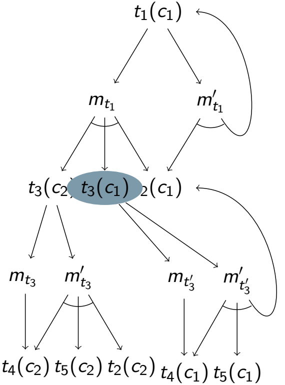

$$
\begin{aligned}
h(m'_{t_3}) &= cost(t_4(c_1)) \\
h(m'_{t'_3}) &= cost(t_4(c_1)) \\
&\quad + cost(t_5(c_1)) \\
&\quad + cost(t_2(c_1)) \\
h(t_3(c_1)) &= min\{h(m'_{t_3}), h(m'_{t'_3})\}
\end{aligned}
$$

...

	Strategy	UM-Tr. (21 inst.)			SmartPh. (5 inst.)			Satellite (22 inst.)			Woodw. (11 inst.)			Summary (59 inst.)		
		#s	#o	cost	#s	#o	cost	#s	#o	cost	#s	#o	cost	#s	#o	cost
blind	Uniform	21	21	1.00	4	4	1.00	17	17	1.00	8	8	1.00	50	50	**1.00**
blind	BF	21	21	1.00	4	4	1.00	15	15	1.00	7	7	1.00	47	47	**1.00**
blind	DF	21	21	1.00	5	1	1.60	19	7	2.09	8	4	1.44	53	33	2.09
systems	UMCP_{BF}	21	21	1.00	4	4	1.00	15	15	1.00	7	7	1.00	47	47	**1.00**
systems	UMCP_{DF}	21	21	1.00	4	1	1.60	17	6	2.09	6	4	1.29	48	32	2.09
systems	UMCP_h	21	21	1.00	5	4	1.40	19	11	1.50	7	7	1.00	52	43	1.50
systems	Compile	18	18	1.00	5	5	1.00	21	18	1.10	5	5	1.00	49	46	1.10
systems	Compile_{opt}	16	16	1.00	5	5	1.00	9	9	1.00	5	5	1.00	35	35	**1.00**
A^*	ADD	21	21	1.00	4	1	1.20	21	21	1.00	10	9	1.17	56	52	1.20
A^*	ADD-r	21	21	1.00	5	5	1.00	19	18	1.08	9	4	1.25	54	48	1.25
A^*	Relax	21	21	1.00	5	5	1.00	18	18	1.00	10	8	1.17	54	52	1.17
A^*	OC	21	21	1.00	4	4	1.00	21	21	1.00	10	7	1.17	56	53	1.17
A^*	TDG_m/-rec	21	21	1.00	5	5	1.00	22	21	1.31	9	9	1.00	**57**	56	1.31
A^*	TDG_c/-rec	21	21	1.00	5	5	1.00	18	18	1.00	8	8	1.00	52	52	**1.00**
Greedy-A^*	ADD	21	21	1.00	4	0	1.20	21	20	1.09	10	9	1.17	56	50	1.20
Greedy-A^*	ADD-r	21	21	1.00	5	5	1.00	20	17	1.10	10	4	1.25	56	47	1.25
Greedy-A^*	Relax	21	21	1.00	5	5	1.00	18	15	1.10	10	4	1.25	54	45	1.25
Greedy-A^*	OC	21	21	1.00	4	4	1.00	22	21	1.09	10	7	1.22	**57**	53	1.22
Greedy-A^*	TDG_m/-rec	21	21	1.00	5	5	1.00	22	17	1.31	9	8	1.08	**57**	51	1.31
Greedy-A^*	TDG_c	21	21	1.00	5	5	1.00	20	20	1.00	10	10	1.00	56	56	**1.00**
Greedy-A^*	TDG_c-rec	21	21	1.00	5	5	1.00	20	20	1.00	11	11	1.00	**57**	**57**	**1.00**

Summary:

- Introduced the first admissible heuristic for standard HTN and hybrid planning.
- The proposed heuristic(s) perform best both in terms of coverage and plan quality.

Also in the paper and poster:

- A variant of the heuristic tailored to hybrid planning systems.
- Investigation of TDG recomputation to improve heuristic accuracy.