Speech about Dipoma Thesis

Solving Non-Deterministic Planning Problems with Pattern Database Heuristics

(Anwendung von Pattern-Database-Heuristiken zum Lösen nichtdeterministischer Planungsprobleme)

Author: Pascal Bercher
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Problem Formulation (informal)

given: Non-deterministic planning problem $\mathcal{P}$.
desired: Strong plan.

chosen procedure: Heuristic search (via AO* algorithm).
chosen heuristic: Pattern database heuristics (abstraction heuristics).

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Non-deterministic planning problem $\mathcal{P} = (Var, A, s_0, G)$ with:

- Var, finite set of state variables.
  $S = 2^{Var}$ is the state space.
- A, finite set of actions $a = \langle pre(a), eff(a) \rangle$ and:
  - $pre(a) \subseteq Var$ and
  - $eff(a) = \{ \langle add_i, del_i \rangle \mid add_i, del_i \subseteq Var \text{ and } i \in \{1, \ldots, n\} \}$.
  - Its application (if $pre(a) \subseteq s$) leads to:
    $app(s, a) = \{ (s \cup add) \setminus del \mid \langle add, del \rangle \in eff(a) \}$
  - The effect variables of a are $effvar(a) = \bigcup_{i \in \{1,\ldots,n\}} add_i \cup del_i$
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AND/OR graphs:
$\mathcal{P}$ induces an AND/OR graph (hypergraph) $\mathcal{G} = (V, C)$ with:

- $V = S \; (= 2^{Var})$, set of nodes and
- C, set of connectors.
  For each $v \in V$ is $c = (v, app(v, a)) \in C$, if $pre(a) \subseteq v$.
  We call $v = pred(c)$ and $app(v, a) = succ(c)$.

Solution graphs:
Restriction to those AND/OR graphs, which represent a strong plan.

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A solution graph $\mathcal{G} = (V, C)$ of $\mathcal{P} = (Var, A, s_0, G)$ is a connected, *cycle-free* AND/OR graph with:

- $s_0 \in V$,
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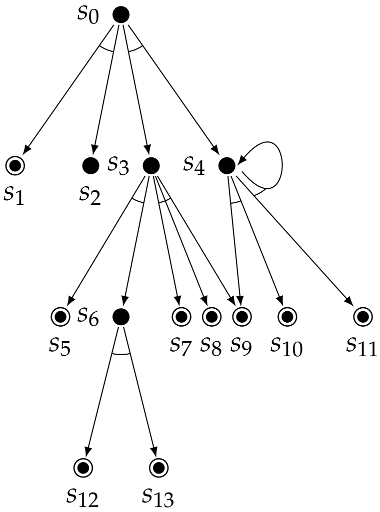
AND/OR Graphs, Solution Graphs, (Non-)Examples



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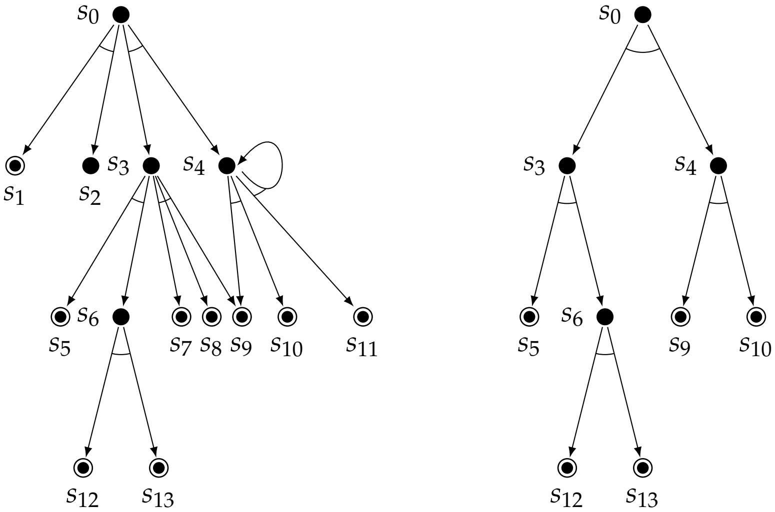

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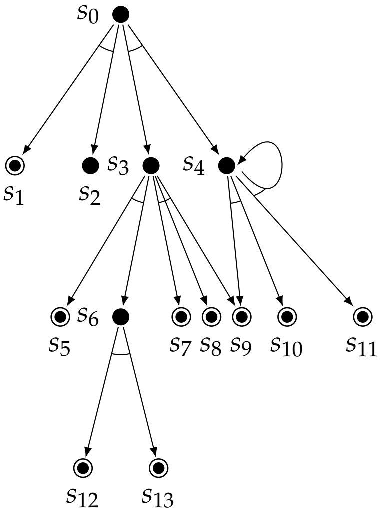

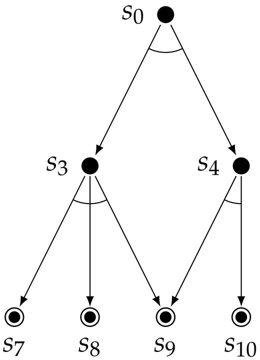

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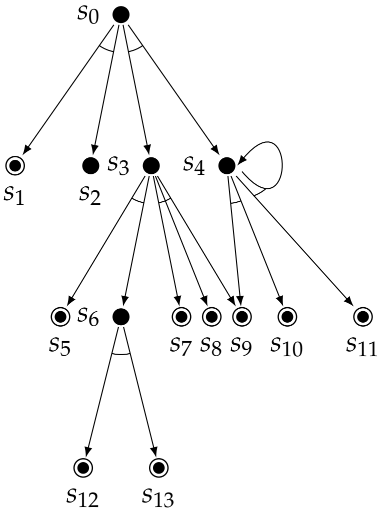

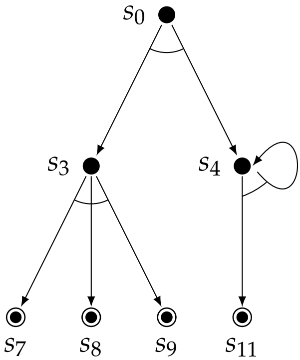

AO* Algorithm, informal

Forward step:

- Traverse graph using only marked connectors and find non-expanded leef with maximal heuristic value (fail first).
- Expand this leef.

Backward step:

- Update cost value of nodes and update markings.
- Optimal cost value for $v \in V$: $cost^*(v) := \min_{\mathcal{G}} height(\mathcal{G})$, where the $\mathcal{G}$'s are solution graphs for v.

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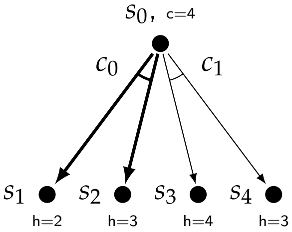

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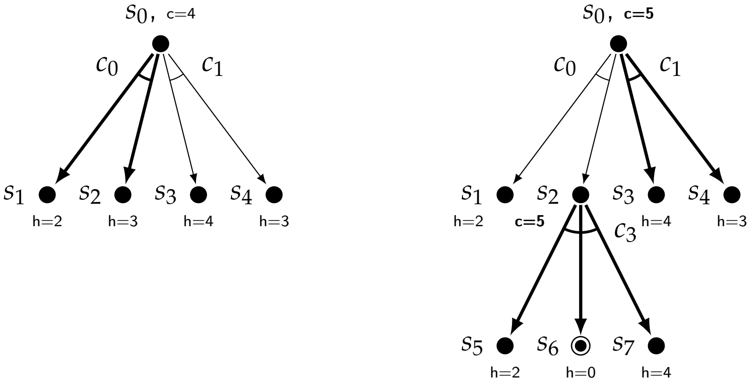

Preprocessing:

- Simplify problem via abstraction.
- For each abstraction: Solve the problem completely.
- For each abstract state: Save its cost in Pattern Database.

During the Search:

- Access the abstract states to use their cost to calculate heuristic.

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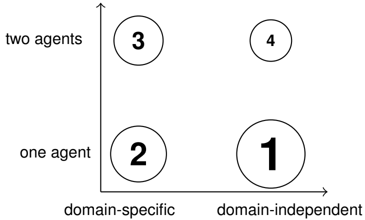

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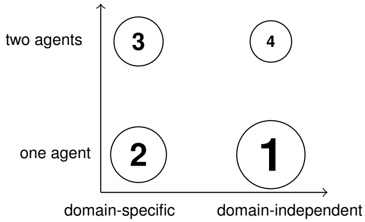

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Definition:
The abstraction $\mathcal{P}^i = (Var^i, A^i, s_0^i, G^i)$ is equal to the planning problem $\mathcal{P}$, restricted to the pattern $P_i \subseteq Var$.

It holds:

- $Var^i := P_i$,
- For $s \in S$ is $s^i := s \cap P_i$ and for $var \subseteq Var$ is $var^i := var \cap P_i$, respectively.
- $a^i := \langle pre(a)^i, \{ \langle add^i, del^i \rangle \mid \langle add, del \rangle \in eff(a) \} \rangle$ for $a \in A$. Then, $A^i := \{ a^i \mid a \in A \}$.
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Calculation of the Pattern Database

For a state s^i and $s \in S$, its heuristic h^i is

$$h^i(s^i) := cost^*(s^i) := \min_{\mathcal{G}} height(\mathcal{G}),$$

where the $\mathcal{G}$'s are solution graphs for s^i.

Calculation process:

- Calculate the complete AND/OR graph of $\mathcal{P}^i$.
- Solve it by Value Iteration.

Question:
How to calculate $h(s)$, if there are multiple patterns?

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Calculation of the heuristic value (1)

given:
Set of patterns $P := \{P_1 \ldots, P_m\}$.

It holds: $h_1(s) := \max_{i \in \{1,\ldots,m\}} h^i(s^i)$ is admissible.

Question:
How to generate a heuristic that is more informed?

Answer:
By using Additivity.

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The set $P := \{P_1, \ldots, P_k\}$ with $k \in \mathbb{N}$ is additive, if for all states $s \in S$ holds $\sum_{i=1}^{k} h^i(s^i) \leq cost^*(s)$.

Theorem, known from classical planning by Edelkamp (2001):

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If for all $a \in A$ and for all patterns $P_i \in P$ holds:

If $P_i \cap effvar(a) \neq \emptyset$, then it holds for all $P_j \in P$ with $P_j \neq P_i$, that $P_j \cap effvar(a) = \emptyset$.

Then the patterns of P are additive.

This theorem also applies to non-deterministic planning problems. (Proof by induction, omitted)

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Theorem, known from classical planning by Edelkamp (2001):

Theorem:
If for all $a \in A$ and for all patterns $P_i \in P$ holds:

If $P_i \cap effvar(a) \neq \emptyset$, then it holds for all $P_j \in P$ with $P_j \neq P_i$, that $P_j \cap effvar(a) = \emptyset$.

Then the patterns of P are additive.

This theorem also applies to non-deterministic planning problems. (Proof by induction, omitted)

Calculation of the heuristic value (2)

given:
Set P of patterns $P := \{P_1 \ldots, P_m\}$ and partition M in additive patterns, i.e. $M := \{M_1, \ldots, M_m\}$ sets of patterns with $\bigcup_{i \in \{1,\ldots,m\}} M_i = P$ and the M_i are additive.

(Now: Identification of s^{P_i} and h^{P_i} with s^i and h^i.)

It holds:

$$h(s) := \max_{M_i \in M} \sum_{P \in M_i} h^P(s^P) \text{ is admissible.}$$

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Open Question:

How to find the set P of pattens, or rather a suitably partition M of P?

$\longrightarrow$

(Still) manually. Automation via local search in principle possible. Cf. Haslum et al. (2005,2007), Edelkamp (2006).

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- Tireworld
  (no additivity)
- Chain of Rooms
  (additivity: sequential subproblems)
- Coin Flip
  (additivity: parallel subproblems)

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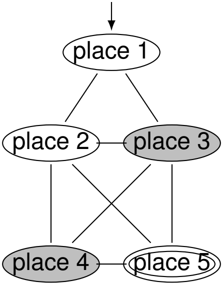
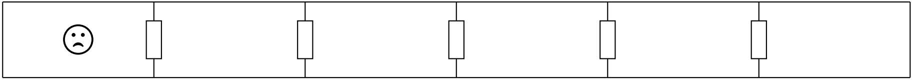
Tireworld, problem description



Actions:

- Use street (non-deterministically: flat tire).
- Take spare tire (if present).
- Change spare (if flat tire and spare present).

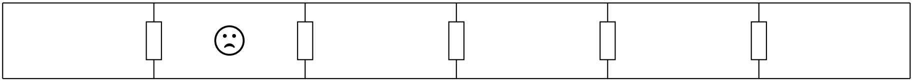
Chain of Rooms, problem description



actions:

- Go into neighboring room, if door is open.
- Turn light on, if it is off
  (non-deterministically: door open/closed).
- Open door.

Chain of Rooms, problem description



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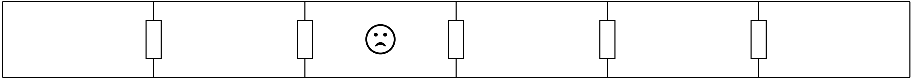

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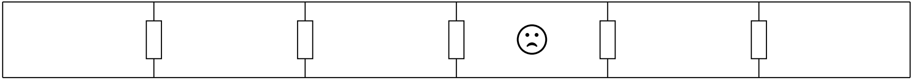

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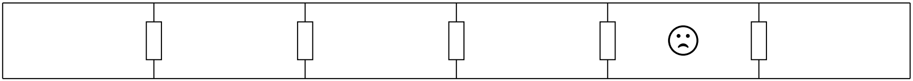

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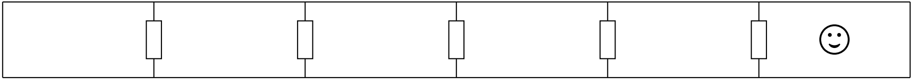

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Coin Flip, problem description

given:

- *n* coins, all initially in a bag.
- Actions:
  - Flip coin, if not flipped before.
  - Reverse coin, if flipped before.

desired:

Strategy, that all coins show heads.

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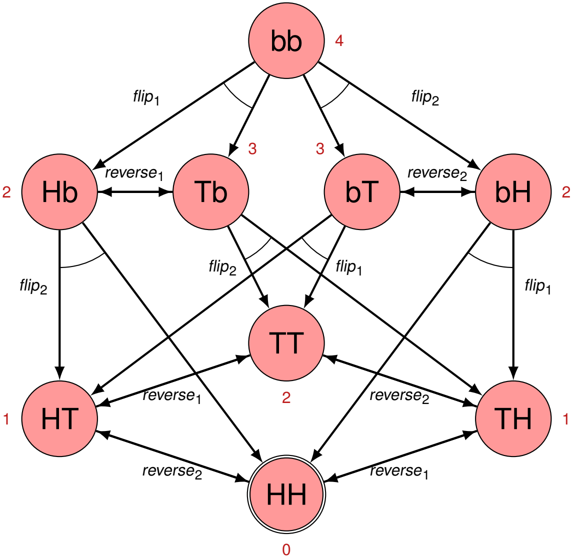
Coin Flip (two coins), example for additive patterns



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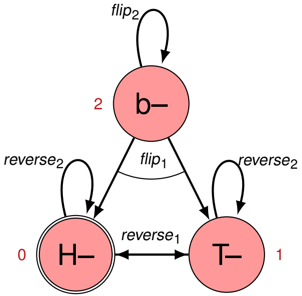
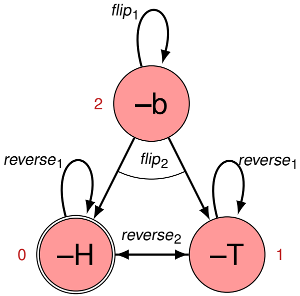


$$h^{P_1}(bb^{P_1}) = h^{P_1}(b-) = 2$$

Coin Flip (two coins), example for additive patterns



$$h^{P_2}(bb^{P_2}) = h^{P_2}(-b) = 2 \qquad \Rightarrow$$

$$h(bb) = h(bb^{P_1}) + h(bb^{P_2}) = h^{P_2}(b-) + h^{P_2}(-b) = 2 + 2 = 4$$

Comparison between:

- AO* algorithm and *no heuristik*,
- AO* algorithm and *adversarial FF heuristic*,
- AO* algorithm and *pattern database heuristic*,

Comparison possible to:

- POND: Partially Observable Nondeterministic Planner (Bryce et al., 2006)
- MBP: Model Based Planner (Cimatti et al., 2003)
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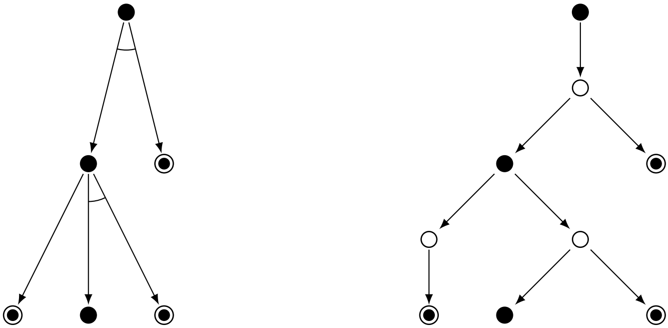
The planner uses explicite AND/OR nodes and edges instead of only one sort of nodes and connectors:



Results: Tireworld

#places	uninformed			adv. FF heuristic			PDB heuristic				
	time	RAM	nodes	time	RAM	nodes	time pre	time search	time	RAM	nodes
4	**0**	**0**	85	**0**	**0**	62	0	0	**0**	**0**	**46**
6	**0**	**0**	84	**0**	**0**	47	2	0	2	8	**37**
8	**0**	1	153	**0**	**0**	**43**	1	0	1	6	**43**
10	**0**	1	293	**0**	**0**	96	2	0	2	7	**67**
20	**0**	4	504	**0**	**1**	**126**	2	0	2	8	128
40	93	2097	115541	**6**	**117**	**6451**	3	6	9	243	12827
60	2	196	9088	**1**	**24**	**1086**	2	0	2	41	1565
80	1	163	5924	**0**	**26**	915	1	0	2	30	**746**
100	17	745	20249	**1**	**42**	**1101**	1	0	2	50	1154
120	–	–	–	17	464	10739	1	1	**3**	**81**	**1632**
140	23	1584	33418	5	90	1849	2	0	**2**	**66**	**1202**
160	–	–	–	8	205	3914	2	0	**3**	**72**	**1175**
180	11	552	9599	**2**	**62**	**1055**	2	2	4	136	2239
200	41	1622	22175	5	130	1746	2	1	**3**	**93**	**1081**

– := out of memory (4 GB)

Ten patterns: Each pattern contains the goal place, the spare, the flat tire and seven random places.

Results: Chain of Rooms

#rooms	uninformed			adv. FF heuristic			PDB heuristic				
	time	RAM	nodes	time	RAM	nodes	time pre	time search	time	RAM	nodes
4	**0**	**0**	38	**0**	**0**	**30**	0	0	**0**	**0**	**30**
6	**0**	**0**	91	**0**	**0**	62	0	0	**0**	**0**	**57**
8	**0**	1	170	**0**	**0**	109	0	0	**0**	**0**	**81**
10	**0**	**1**	272	**0**	**1**	169	0	0	**0**	**1**	**147**
20	**0**	6	1142	**0**	**3**	643	1	0	1	**3**	**464**
40	**1**	40	4682	8	20	2494	3	0	4	**18**	**2043**
60	**5**	121	10621	40	59	5543	9	1	10	**52**	**4827**
80	**17**	278	18962	122	131	9793	16	3	20	**121**	**8804**
100	43	533	29702	300	251	15244	30	9	**39**	**230**	**13983**
120	92	909	42841	609	443	21893	43	19	**62**	**394**	**20367**
140	162	1390	58382	1164	686	29743	63	37	**101**	**617**	**27944**
160	257	2090	76322	2054	994	38794	94	63	**157**	**902**	**36723**
180	468	2986	96661	3369	1457	49043	127	98	**225**	**1283**	**46707**
200	–	–	–	5855	1961	60493	164	154	**319**	**1763**	**57884**

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Patterns: Four neighboring rooms per pattern.

Results: Coin Flip

#coins	uninformed			adv. FF heuristic			PDB heuristic				
	time	RAM	nodes	time	RAM	nodes	time pre	time search	time	RAM	nodes
4	**0**	1	349	**0**	1	313	0	0	**0**	**0**	**69**
6	**0**	11	4809	**0**	8	3374	0	0	**0**	**0**	**161**
8	18	145	58377	3	46	18641	0	0	**0**	**1**	**293**
10	1102	1542	588813	77	483	186221	0	0	**0**	**1**	**465**
20	–	–	–	–	–	–	0	0	**0**	**7**	**1925**
40	–	–	–	–	–	–	1	1	**2**	**49**	**7845**
60	–	–	–	–	–	–	3	6	**9**	**161**	**17765**
80	–	–	–	–	–	–	6	18	**24**	**384**	**31685**
100	–	–	–	–	–	–	12	45	**57**	**714**	**49605**
120	–	–	–	–	–	–	18	96	**114**	**1176**	**71525**
140	–	–	–	–	–	–	28	163	**192**	**1784**	**97445**
160	–	–	–	–	–	–	39	289	**329**	**2589**	**127365**
180	–	–	–	–	–	–	58	–	–	–	–
200	–	–	–	–	–	–	74	–	–	–	–

– := out of memory (4 GB)

Patterns: Two coins per pattern.

Summary:

- Additivity criterion also applies to non-deterministic planning.
- Pattern database heuristics (therefore) can achieve good results (depending on decomposition).

Outlook:

- Finding strong *cyclic* plans.
- Automated pattern selection.
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Thanks for your attention!

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