Solving Non-deterministic Planning Problems with Pattern Database Heuristics

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Given: A non-deterministic planning problem.

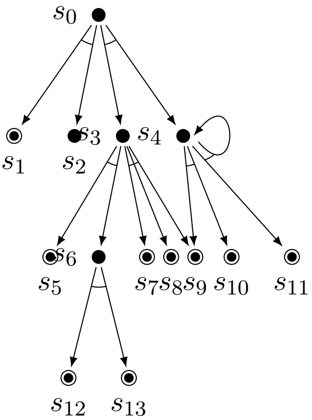
Desired: An acyclic solution, i.e. a strong plan.
(Success, regardless of non-deterministic outcome.)

Given:

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
  - $eff(a) = \{ \langle add_i, del_i \rangle \mid add_i, del_i \subseteq Var \text{ and } i \in \{1, \dots, n\} \}$.
  - Its application (if $pre(a) \subseteq s$) leads to:
    $app(s, a) = \{ (s \setminus del) \cup add \mid \langle add, del \rangle \in eff(a) \}$
- $s_0 \in S$, the *initial state*.
- $G \subseteq Var$, the *goal description*.

Desired:
Strong plan.



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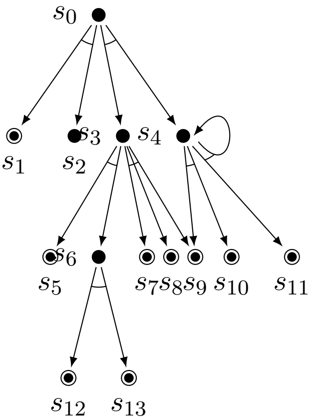

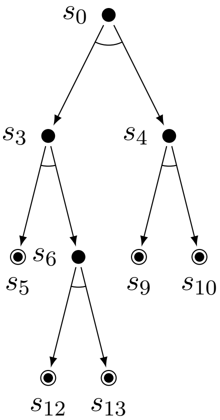

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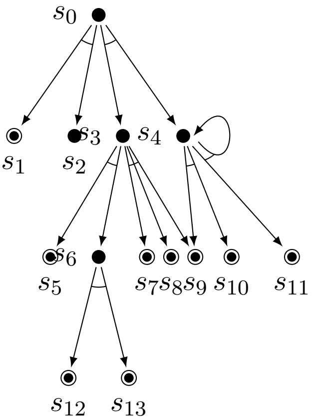

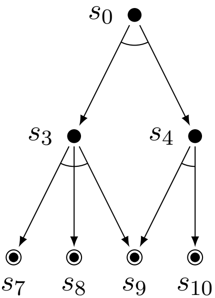

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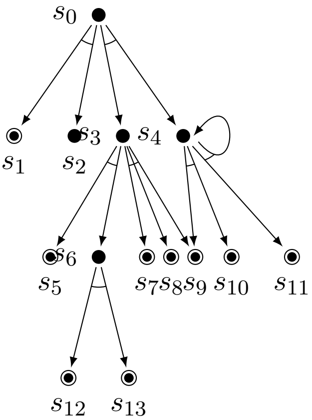
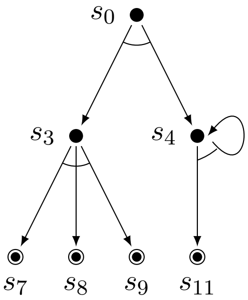
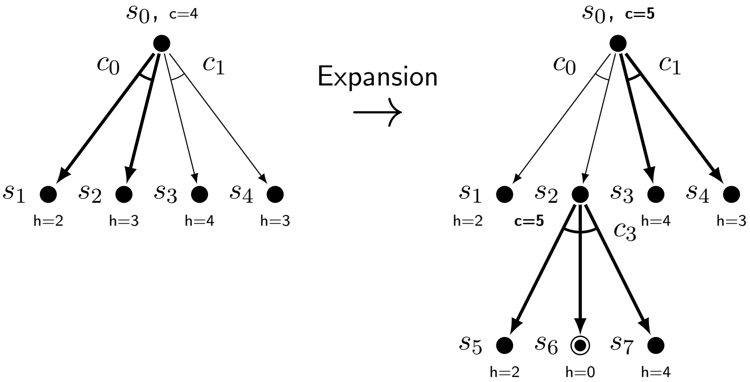
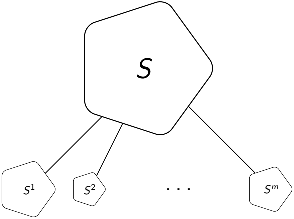




Search Algorithm, modification of AO*



Use abstraction to simplify the problem:



Map the search space S to abstract search spaces S^i with $|S^i| \ll |S|$, f.a. $P_i \in P$, P finite pattern collection.

Compute $h(s), s \in S$, on basis of all $h^i(s^i), P_i \in P$.

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

- $Var^i Var \cap P_i = P_i$,
- For $var \subseteq Var$ let $var^i var \cap P_i$. Then:
  $a^i \langle pre(a)^i, \{ \langle add^i, del^i \rangle \mid \langle add, del \rangle \in eff(a) \} \rangle$ for $a \in A$.
  Now, $A^i \{ a^i \mid a \in A \}$.
- $s_0^i s_0 \cap P_i$
- $G^i G \cap P_i$.

Given: Pattern collection $P = \{P_1 \dots, P_m\}$.

For each pattern $P_i \in P$, calculate true cost value for complete S^i.
Calcuation is done by a complete exhaustive search.

(*True* means: prefer shallow solution graphs.)

Compute: $h(s) \max_{P_i \in P} h^i(s^i)$. ($h$ is admissible.)

Make use of additivity.
A pattern collection P is called *additive*, if for all states $s \in S$:
$\sum_{P_i \in P} h^i(s^i) \leq cost^*(s)$.

Known from classical planning:

Theorem (informal)

If there is no action $a \in A$ that affects variables in more than one pattern from P, then P is additive

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Known from classical planning:

Theorem (formal)

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

If $P_i \cap effvar(a) \neq \emptyset$, then $P_j \cap effvar(a) = \emptyset$ for all $P_j \in P$ with $P_j \neq P_i$, where $effvar(a) = \bigcup_{\langle add, del \rangle \in eff(a)} add \cup del$.

Then P is additive.

$\mathcal{P} = (\{a, b, c, d, e\}, A, \{a\}, \{b, c, d, e\})$ with $A = \{a_1, \ldots, a_9\}$ and:

$$a_1 = \langle \{a\}, \{\langle \{b\}, \{a\} \rangle, \langle \{c\}, \{a\} \rangle\} \rangle$$
$$a_2 = \langle \{b\}, \{\langle \{e\}, \emptyset \rangle, \langle \{d\}, \emptyset \rangle\} \rangle$$
$$a_3 = \langle \{c\}, \{\langle \{e\}, \emptyset \rangle, \langle \{d\}, \emptyset \rangle\} \rangle$$
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Additivity (Example)

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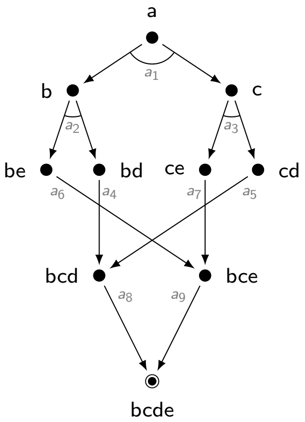
Now, consider the pattern collection $P = \{\{a, b, c\}, \{d, e\}\}$.
Only the effect variables matter!

Additivity (Example, cont'd)



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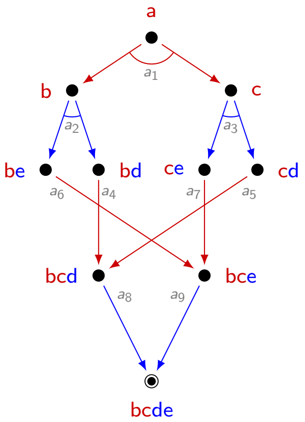

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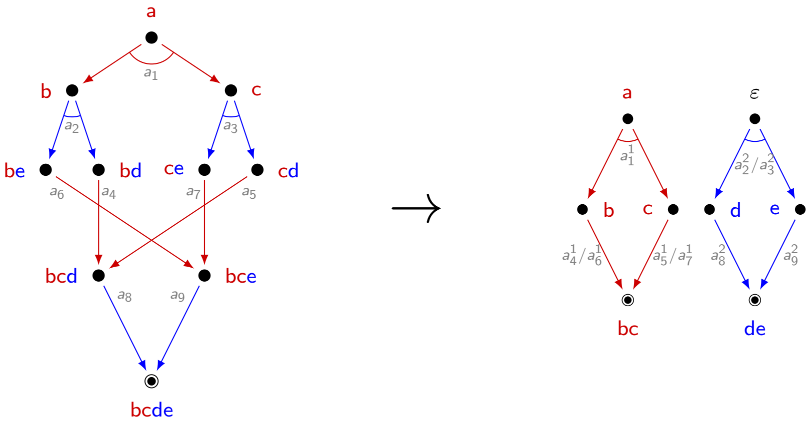

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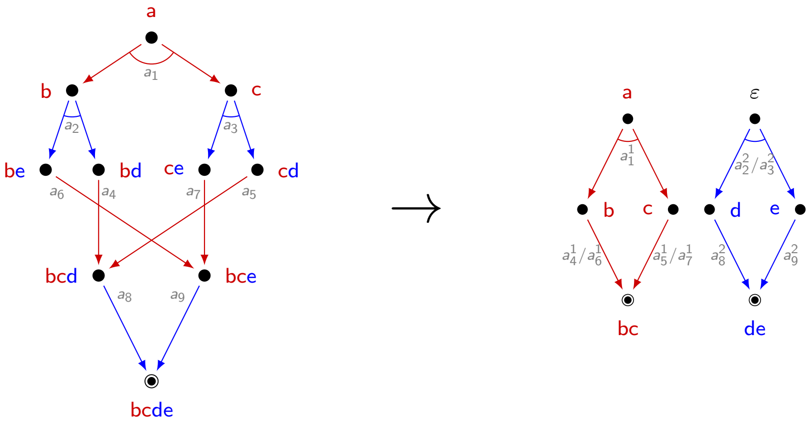


Example:
$h(\{a\}) = h^1(\{a\}^1) + h^2(\{a\}^2) = h^1(\{a\}) + h^2(\emptyset) = 2 + 2 = 4 = cost^*(\{a\})$.

Let $\mathcal{M}$ be a set of additive pattern collections.
$h^{\mathcal{M}}(s) := \max_{P \in \mathcal{M}} \sum_{P_i \in P} h^i(s)$.

$h^{\mathcal{M}}$ (and in particular, every single h^i) is admissible.

How to find $\mathcal{M}$?
Current research. (Here: still domain-dependent by hand.)

Summary

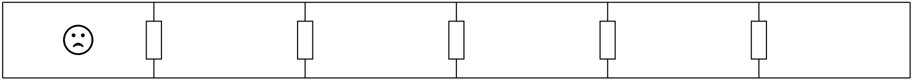
–

Encoded two domains:

- Chain of Rooms
  sequential subproblems, well-informed heuristic.
- Coin Flip
  parallel subproblems, perfectly informed heuristic.

Comparison with GAMER[1]. *Important* differences:

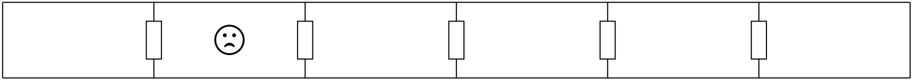
- Optimal solutions[1] vs. suboptimal solutions.
- Regression[1] vs. progression.



Actions:

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

Goal:
Having visited each room at least once.



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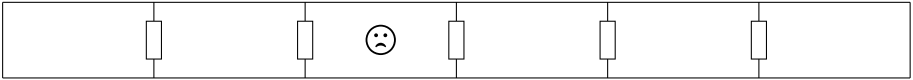

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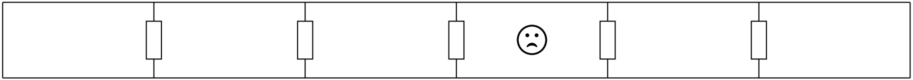

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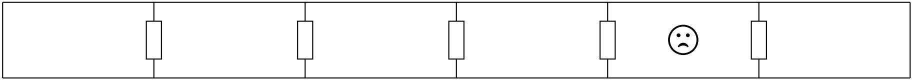

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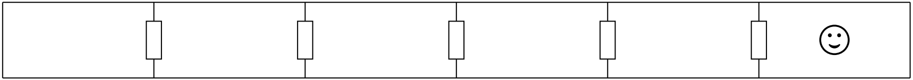

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Chain of Rooms

#rooms	AO* Planner, FF			AO* Planner, PDB						Gamer	
	search	mem	nodes	pre	search	sum	mem	|PDB|	nodes	search	|BDD|
20	2	3	236	4	1	5	3	315	274	6	16699
40	15	13	873	7	2	9	17	679	1138	23	130657
60	69	33	1909	16	6	22	46	1043	2602	—	—
80	250	69	3346	26	15	41	100	1407	4666	—	—
100	655	133	5183	41	33	74	190	1771	7330	—	—
120	1497	214	7419	61	73	134	319	2135	10594	—	—
140	—	—	—	91	117	208	495	2499	14458	—	—
160	—	—	—	127	194	321	736	2863	18922	—	—
180	—	—	—	177	314	491	1050	3227	23986	—	—

Dashes indicate that the time-out of 30 minutes or the memory bound of 1500 MB was exceeded.

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.

Coin Flip

#coins	AO* Planner, FF			AO* Planner, PDB						Gamer	
	search	mem	nodes	pre	search	sum	mem	|PDB|	nodes	search	|BDD|
20	—	—	—	2	1	3	4	60	1125	—	—
40	—	—	—	3	4	7	27	120	4645	—	—
60	—	—	—	4	19	23	85	180	10565	—	—
80	—	—	—	7	60	67	180	240	18885	—	—
100	—	—	—	11	217	328	366	300	29605	—	—
120	—	—	—	18	306	324	597	360	42725	—	—
140	—	—	—	23	533	556	905	420	58245	—	—
160	—	—	—	34	908	942	1307	480	76165	—	—

Dashes indicate that the time-out of 30 minutes or the memory bound of 1500 MB was exceeded.

- Presented fomalization for domain-independent pattern database heuristics in non-deterministic planning.
- Generalization of additivity criterion.
- Benchmarks look promising.

Future Work

- Automatic pattern selection (Bachelor thesis finished).
- Strong plans $\rightarrow$ strong *cyclic* plans.
  - Search algorithm, LAO*.
  - Pattern database heuristics: Admissibility/Additivity?
- Multi-valued state variables.

Thank you!