Solving Non-deterministic Planning Problems with Pattern Database Heuristics

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Given:	A non-deterministic planning problem. (Informally: Initial state, actions, goal states. Nondeterminism: actions may have several outcomes.)
Desired:	A solution to that problem. (Informally: How to reach a goal state, using the actions?)

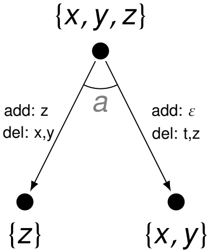
Given:

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*.
  A state $s \in S$ is a goal state iff $s \supseteq G$.

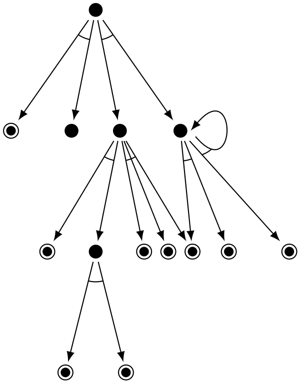
Let $s = \{x, y, z\} \in S$ be a state and $a \in A$ be an action with:

$a = \langle pre(a), eff(a)\rangle$ and
$pre(a) = \{x, y\} \subseteq s$,
$eff(a) = \{ \langle\{z\}, \{x, y\}\rangle, \langle\emptyset, \{t, z\}\rangle \}$.



Desired:

Strong plan. (Success, regardless of non-deterministic outcome.)



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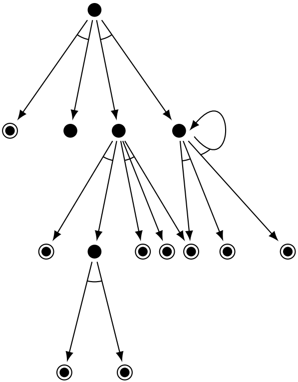

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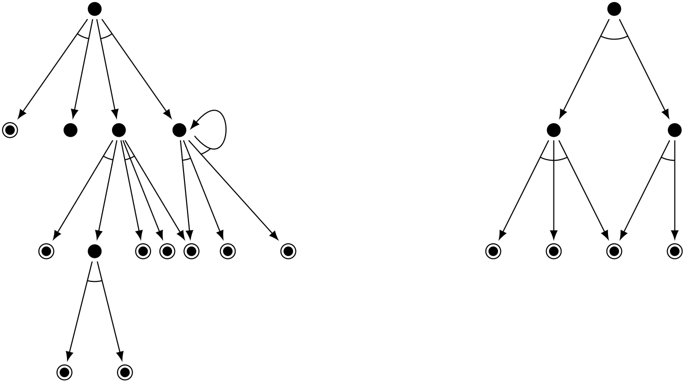

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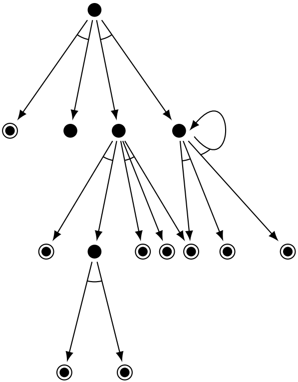
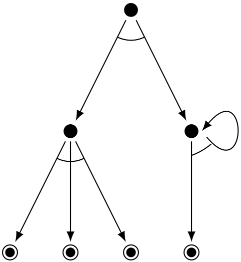
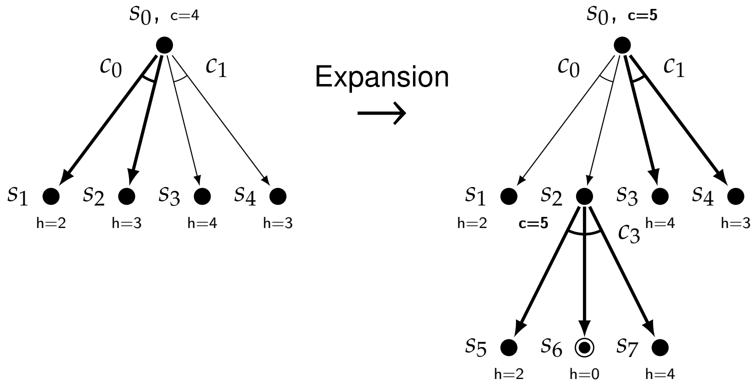
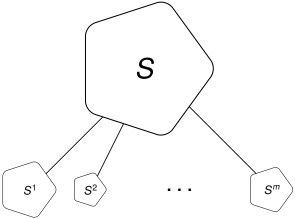




Search Algorithm, modification of AO*



Use abstraction to simplify the problem:



Map the search space S to abstract search spaces S^i with $|S^i| \ll |S|$.

Compute $h(s), s \in S,$ on basis of all $h^i(s^i)$.
Calculation of the h^i is done *before* the search.

Idea: Disregard some (or rather *most of the*) state variables.

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, $A^i := \{ a^i \mid a \in A \}$.
- $s_0^i := s_0 \cap P_i$
- $G^i := G \cap P_i$.

Recall:

- A *pattern* is a set of state variables $P_i \subseteq Var$.
  Then, a *pattern collection* P is a set of patterns.
- Compute $h(s), s \in S$, on basis of all $h^i(s^i), P_i \in P$, P finite pattern collection, i.e. set of patterns.

How to calculate those $h^i(s^i), s^i \in S^i$?

$h^i(s^i)$ is the *true* cost value *cost** of the planning problem $\mathcal{P}^i$.
Calcuation is done by a complete exhaustive search.
(Thus, S^i and therefore P_i have to be small!)

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

How to calculate $h(s), s \in S$?

By using additivity!
A pattern collection P is called *additive*, if for all states $s \in S$:
$\sum_{P_i \in P} h^i(s^i) \leq cost^*(s)$, i.e. if this sum is still admissible.

Known from classical planning:

Theorem (textual description)

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 (mathematical description)

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.

Additivity (Example)

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

$a_1 = \langle\{a\}, \{\langle\{b\}, \{a\}\rangle, \langle\{c\}, \{a\}\rangle\}\rangle$

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Now, consider the pattern collection $P = \{\{a, b, c\}, \{d, e\}\}$.

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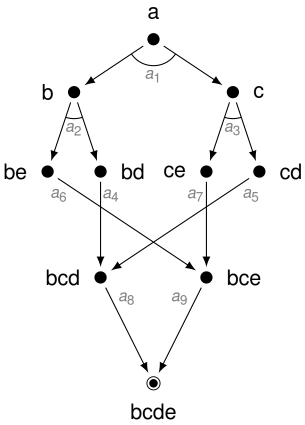
Only the effect variables matter!

Additivity (Example, cont'd)



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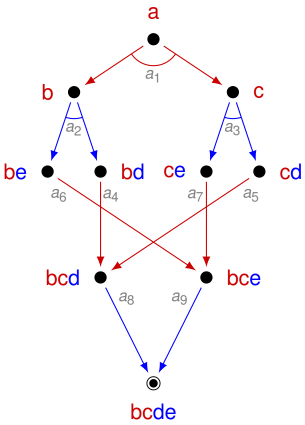

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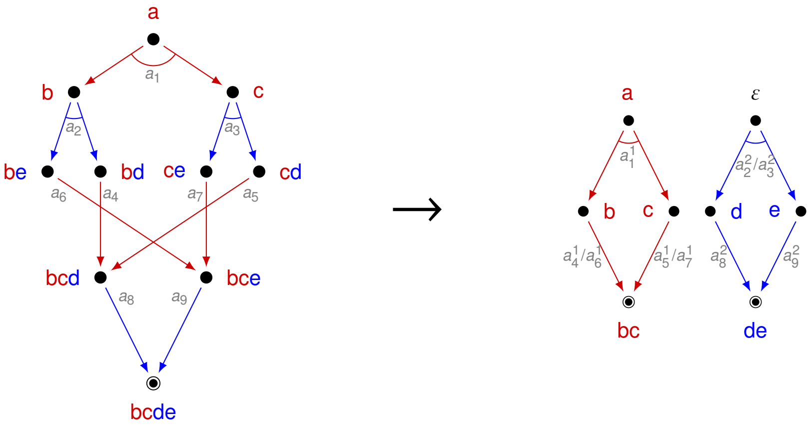
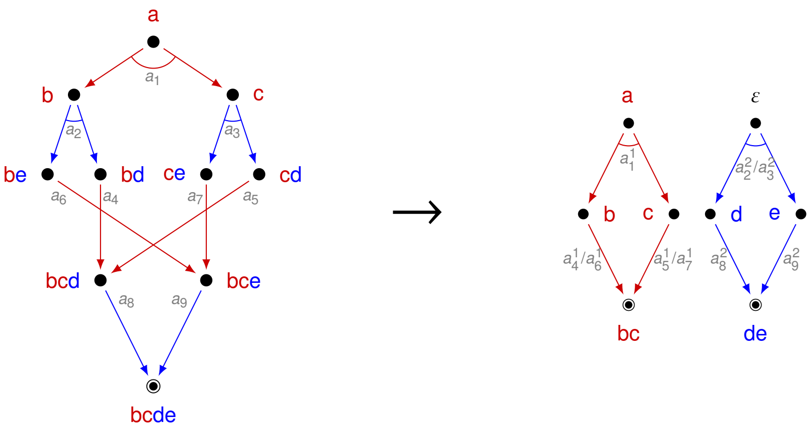


Additivity (Example, cont'd)



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.

$h^{\mathcal{M}}(s) := \max_{P \in \mathcal{M}} \sum_{P_i \in P} h^i(s^i)$.

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

How to find $\mathcal{M}$?

Current research. (Here: still domain-dependent by hand.)

Compared Systems

Encoded two domains and compared:

- Our planner with the heuristic of FF.
- Our planner with the presented pattern database heuristics.
- GAMER.

Important differences between GAMER and our system:

- Optimal solutions vs. suboptimal solutions.
- Regression vs. progression.

Results

- Pattern database heuristic quality is problem dependent:

Domain 1:	Pattern database heuristics about 25% more node expansions than FF heuristic.
Domain 2:	Pattern database heuristics calculate true (perfect) cost value (as opposed to the FF heuristic).

- Calculation time of pattern database heuristic is much smaller than the FF heuristic's. Thus, more problems could be solved.
- Progression with heuristic search seems promising approach. (Note: No comparison to sub-optimal planner, yet.)

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

Future Work

- Automatic pattern selection.
- Strong plans → strong *cyclic* plans.
  - Search algorithm, LAO*.
  - Pattern database heuristics: Admissibility/Additivity?
- Multi-valued state variables.

Thank you!