When Perfect is not Good Enough: On the Search Behaviour of Symbolic Heuristic Search



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Motivation

Symbolic search and *heuristic search* are two successful approaches to optimal planning.

Symbolic Planner

- Symbolic state representation
- Blind search

Heuristic Planner

- Explicit state representation
- Informed search
  - Symbolic heuristic representation

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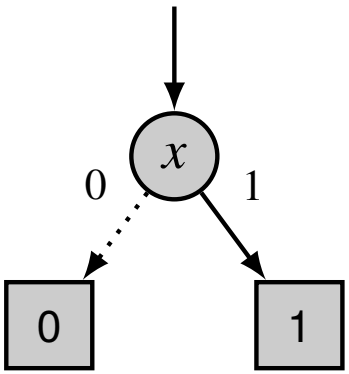
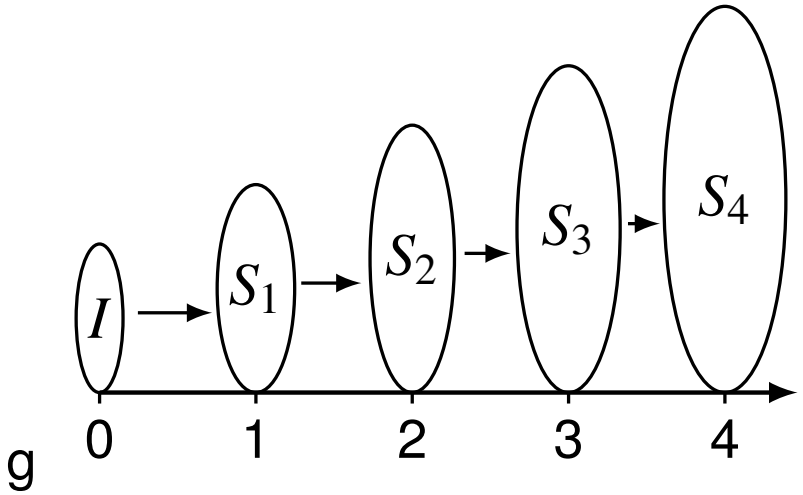
Symbolic Heuristic Planner?

Symbolic Search for Optimal Planning

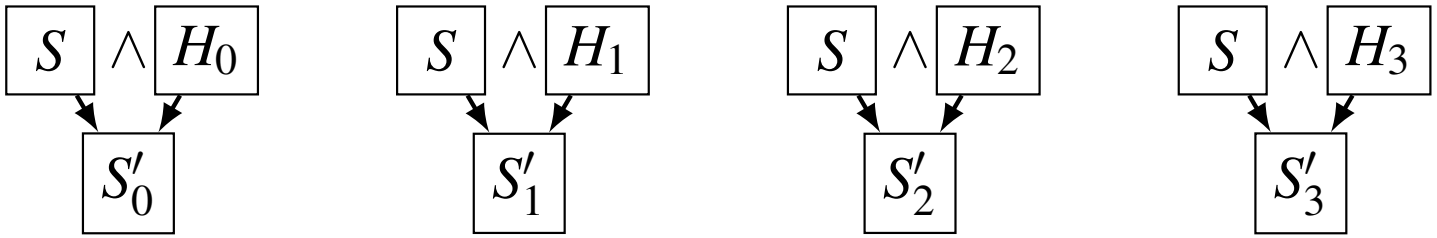
- Operations on sets of states
- $S \subseteq \mathcal{S}$ represented by characteristic function χ_S
- Manipulating $S \mathrel{\hat{=}}$ Transforming χ_S
  - E.g. $S \cap S' \mathrel{\hat{=}} \chi_S \wedge \chi_{S'}$
- Binary Decision Diagrams (BDDs)
- Search performance depends on the size of BDDs

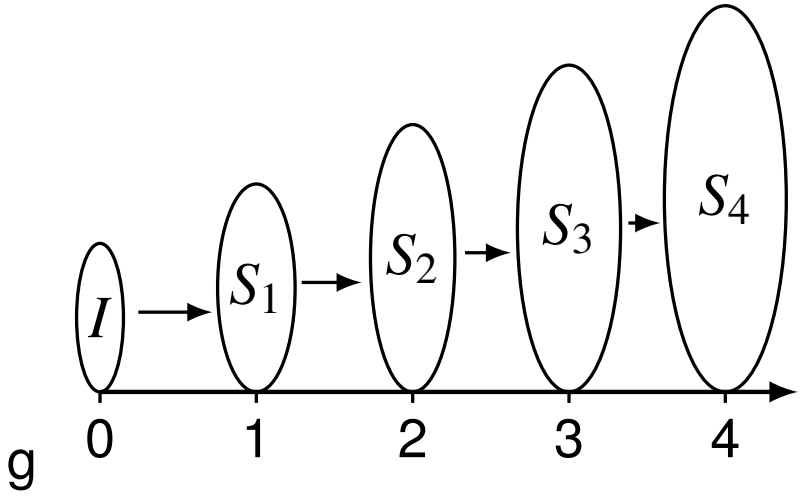




Symbolic Heuristic Search - BDDA*

Given a set of states S, split it according to their h-value $S'_i = S \wedge H_i$.





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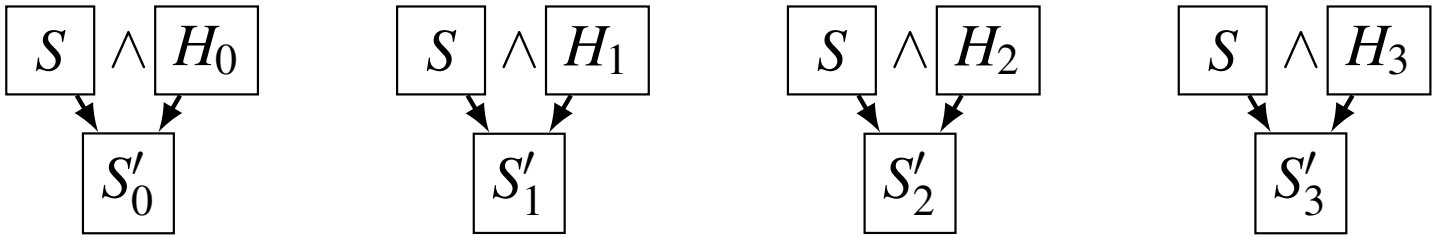

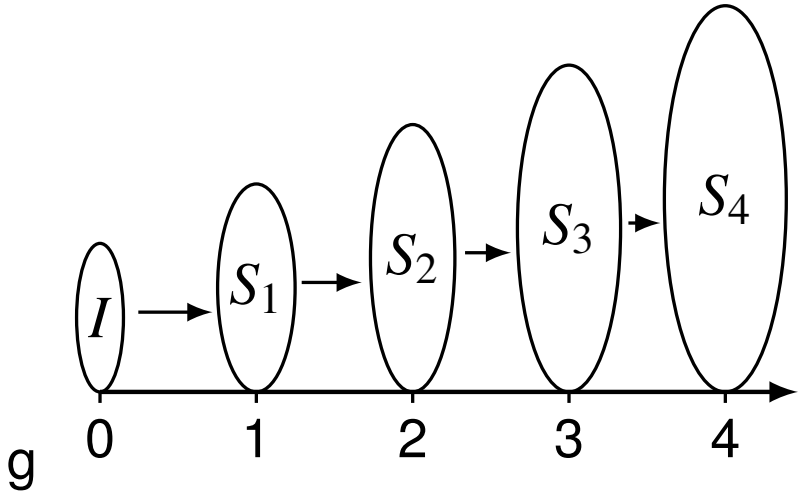

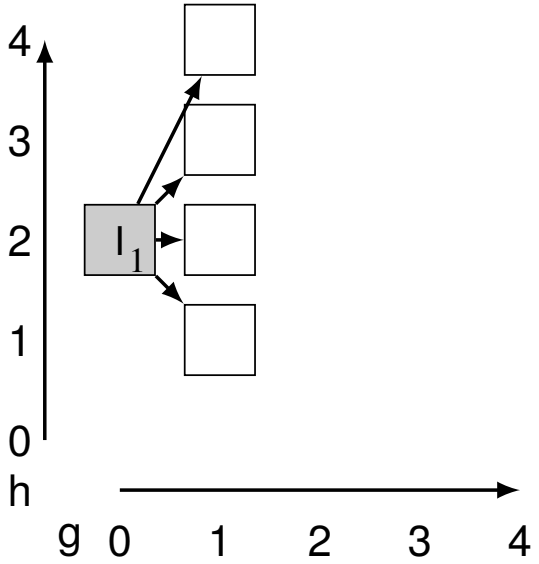

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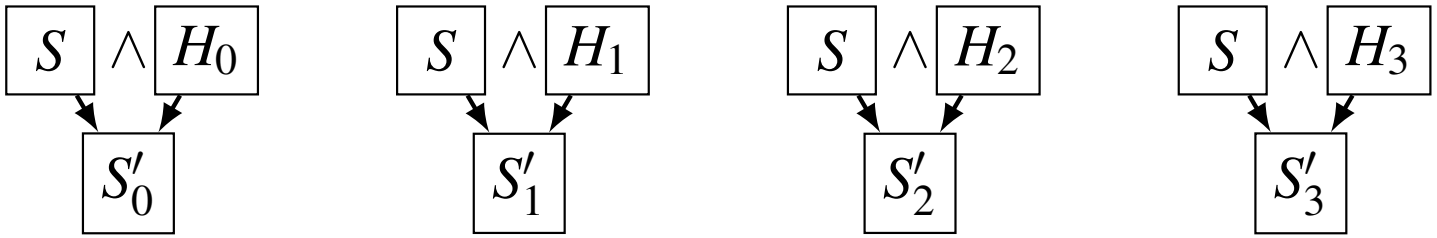

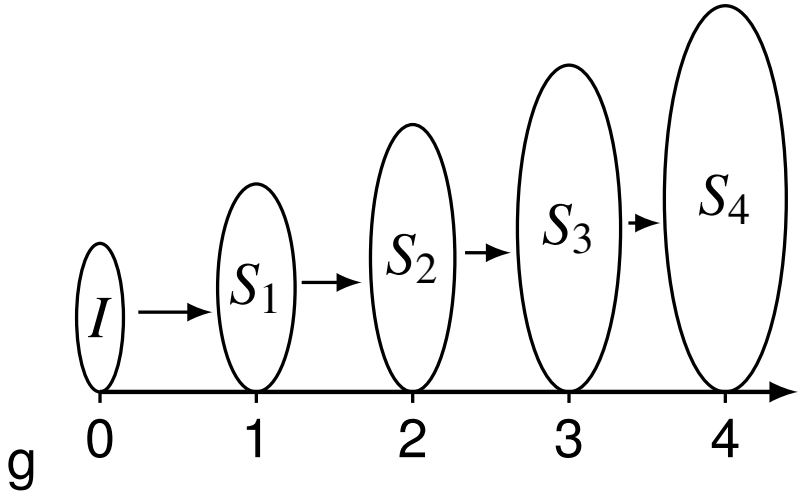

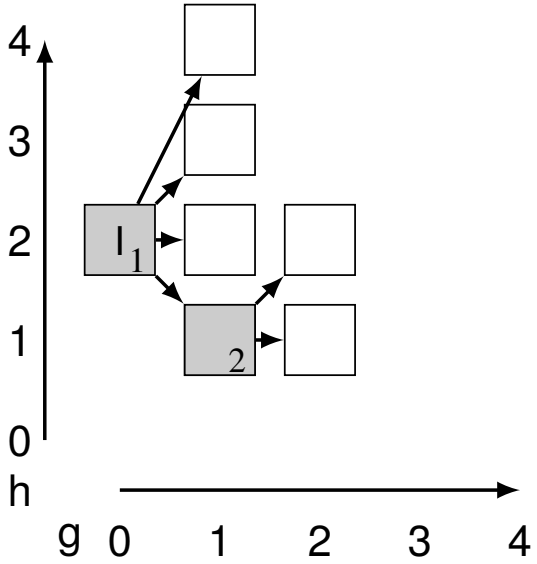

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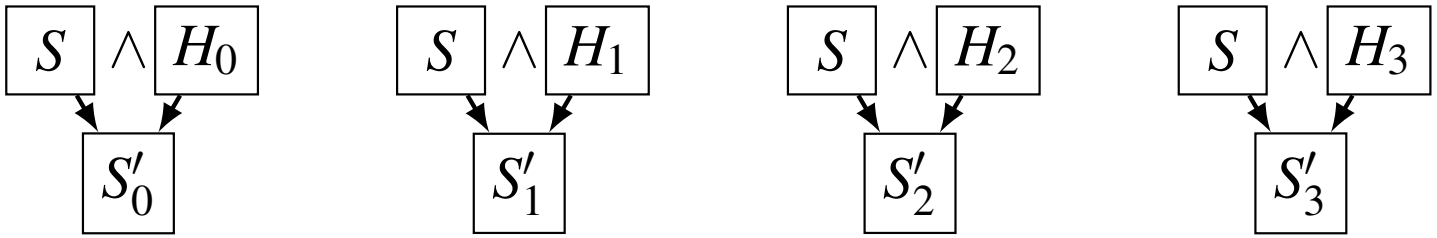

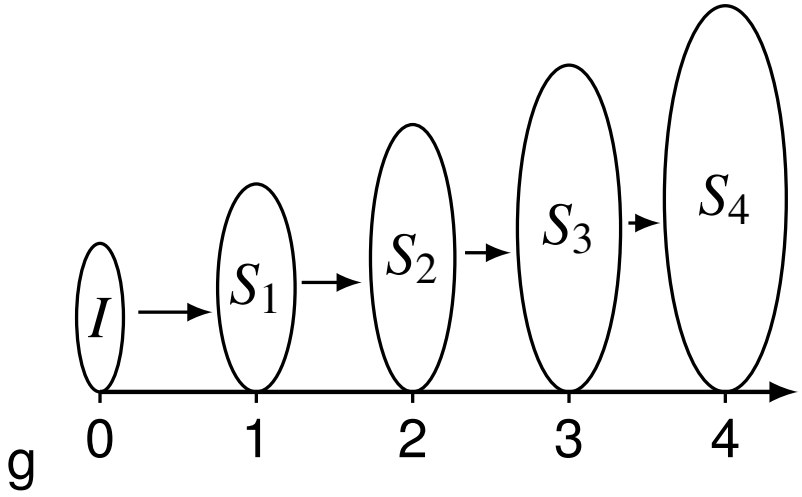

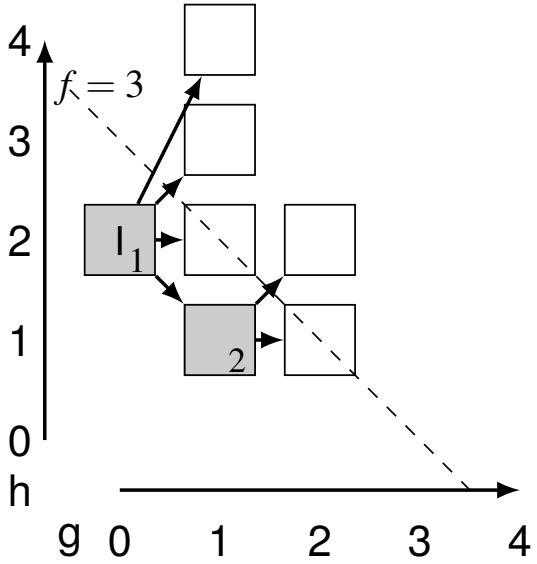

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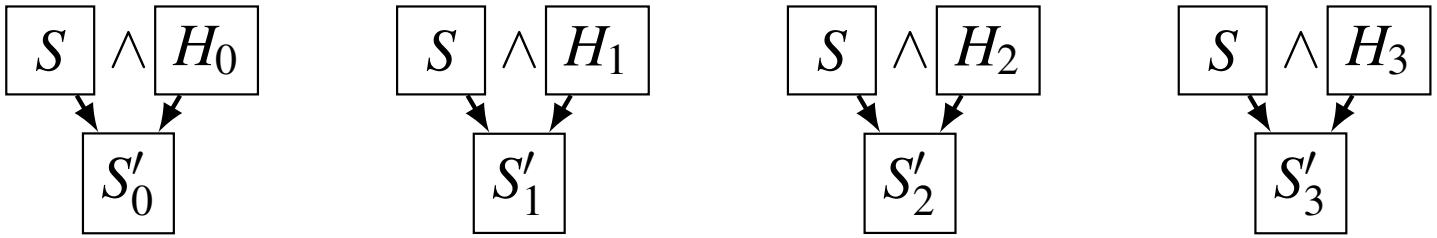

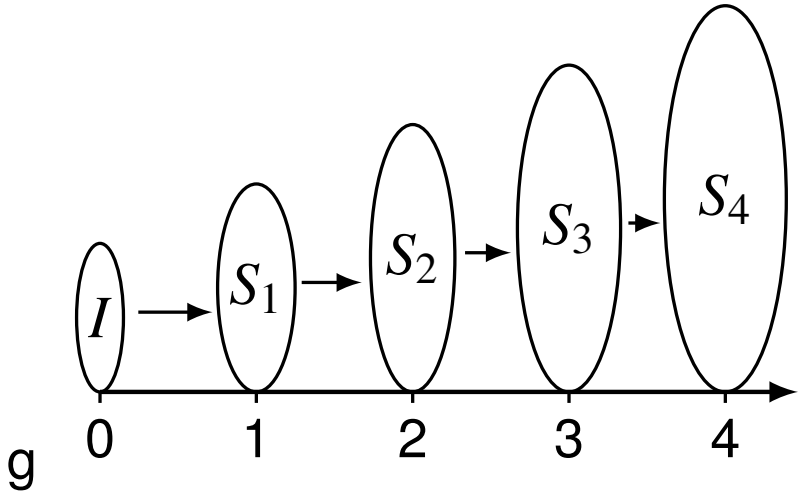

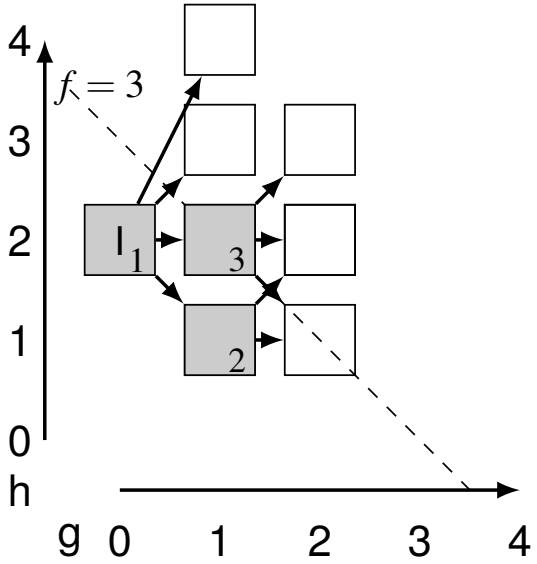

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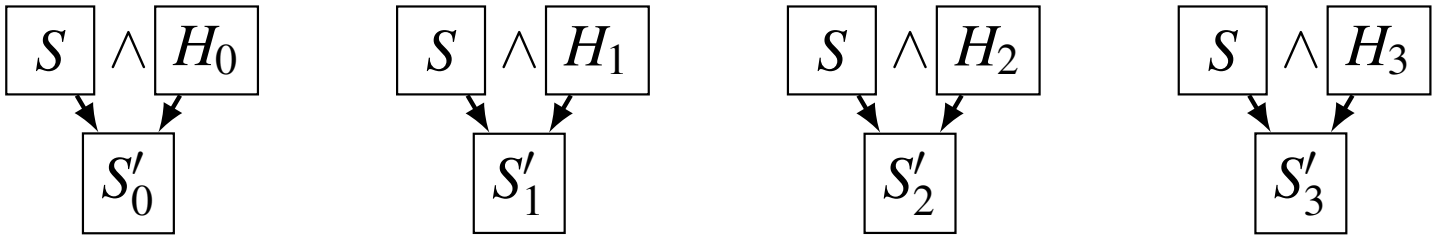

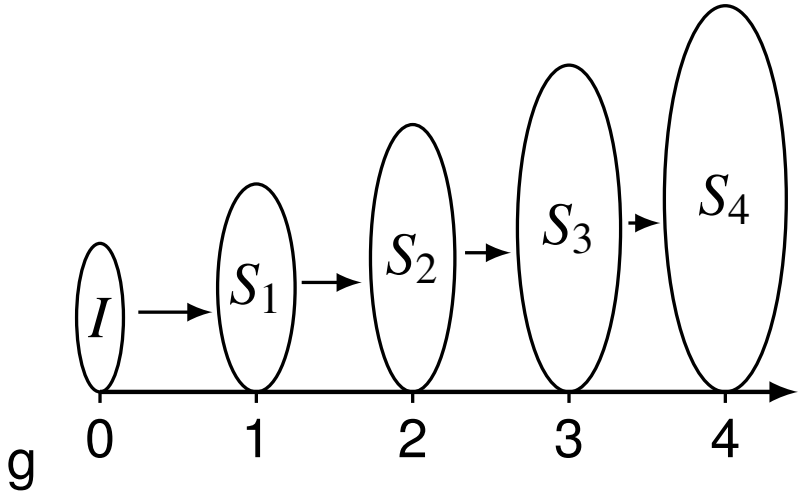

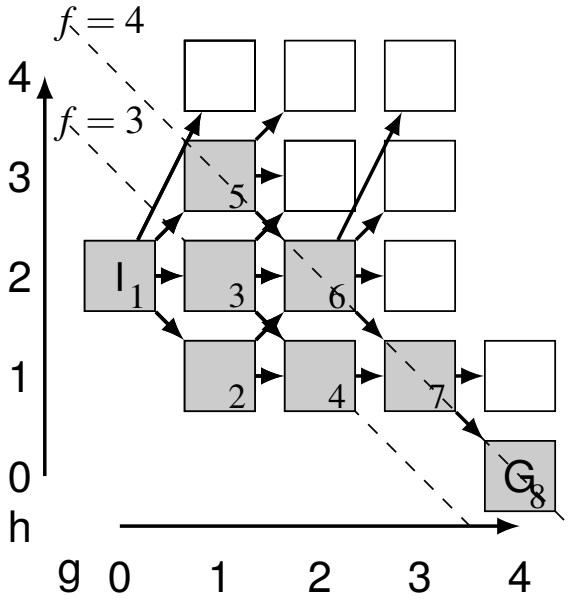

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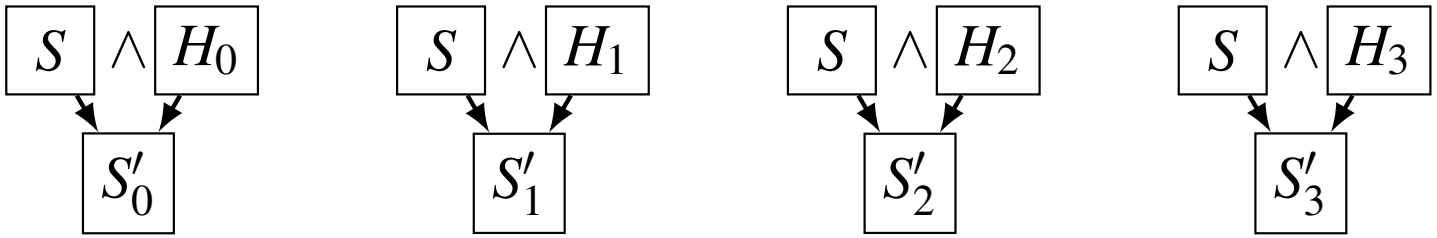

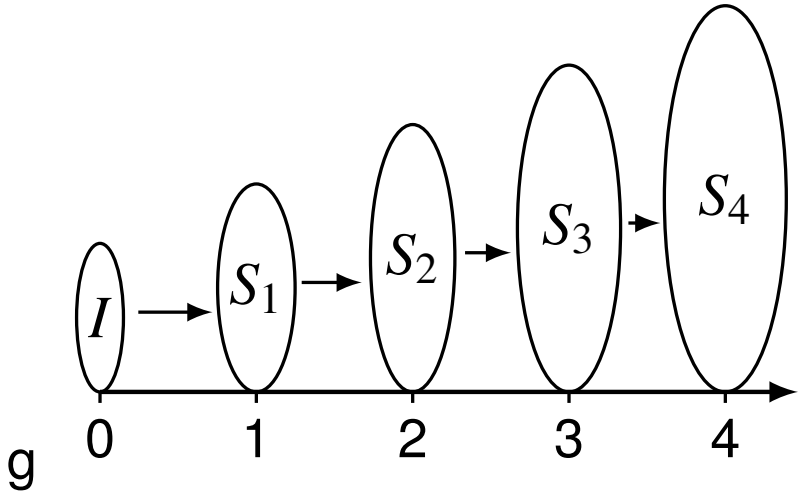

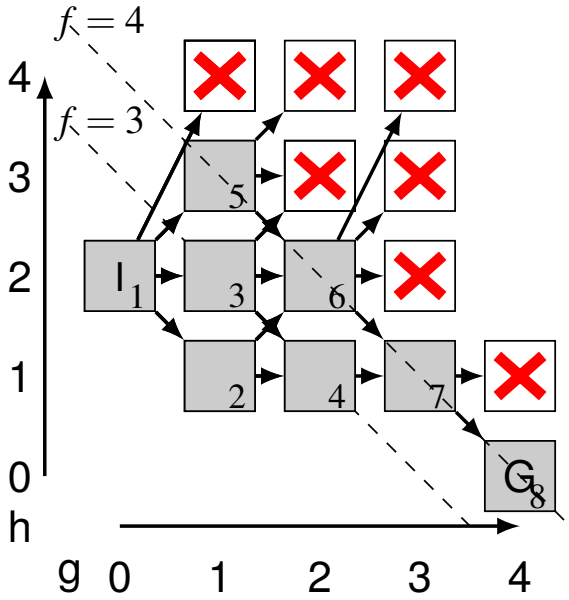

Symbolic Heuristic Search – Performance

- Consistent heuristics reduce the number of necessary state expansions.
- Heuristic computation and state evaluation are expensive [JVB08].

Oberservation

A BDD $B_{S'}$ can be larger than BDD B_S although the set of states S' is a strict subset of S, i.e. $S' \subsetneq S$.

$\rightsquigarrow$ In symbolic search, the search performance is not directly related to the number of explicit states that have to be expanded.

Theoretical Results

Splitting BDDs according to heuristic values can increase or decrease the sizes of the resulting BDDs.

- In the worst case exponentially
- Even with the perfect heuristic $h^\star$ □

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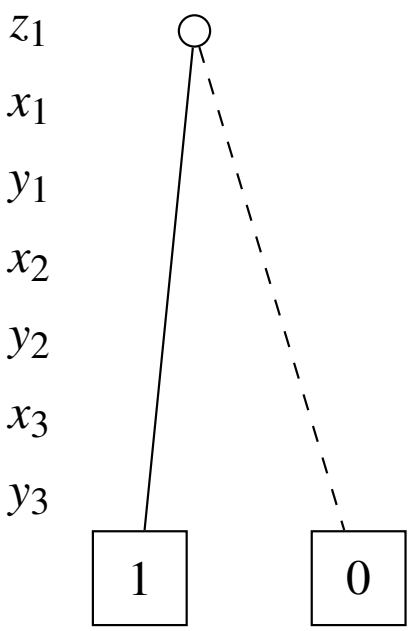

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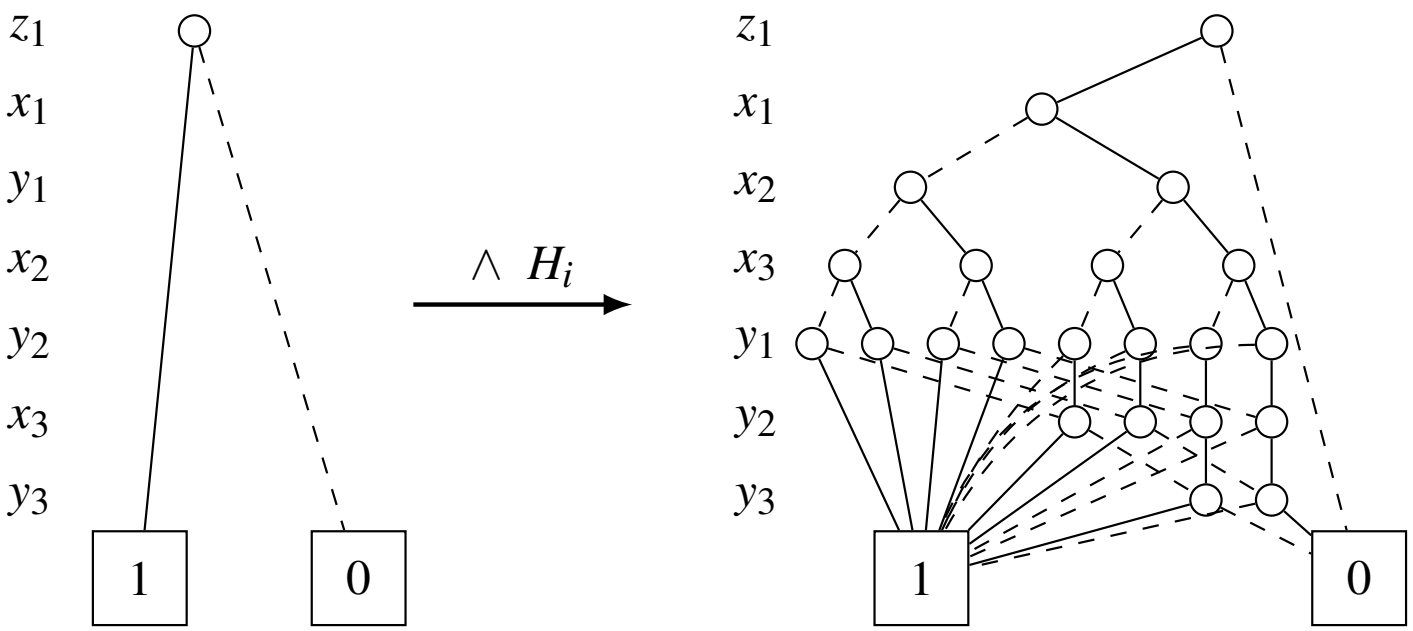

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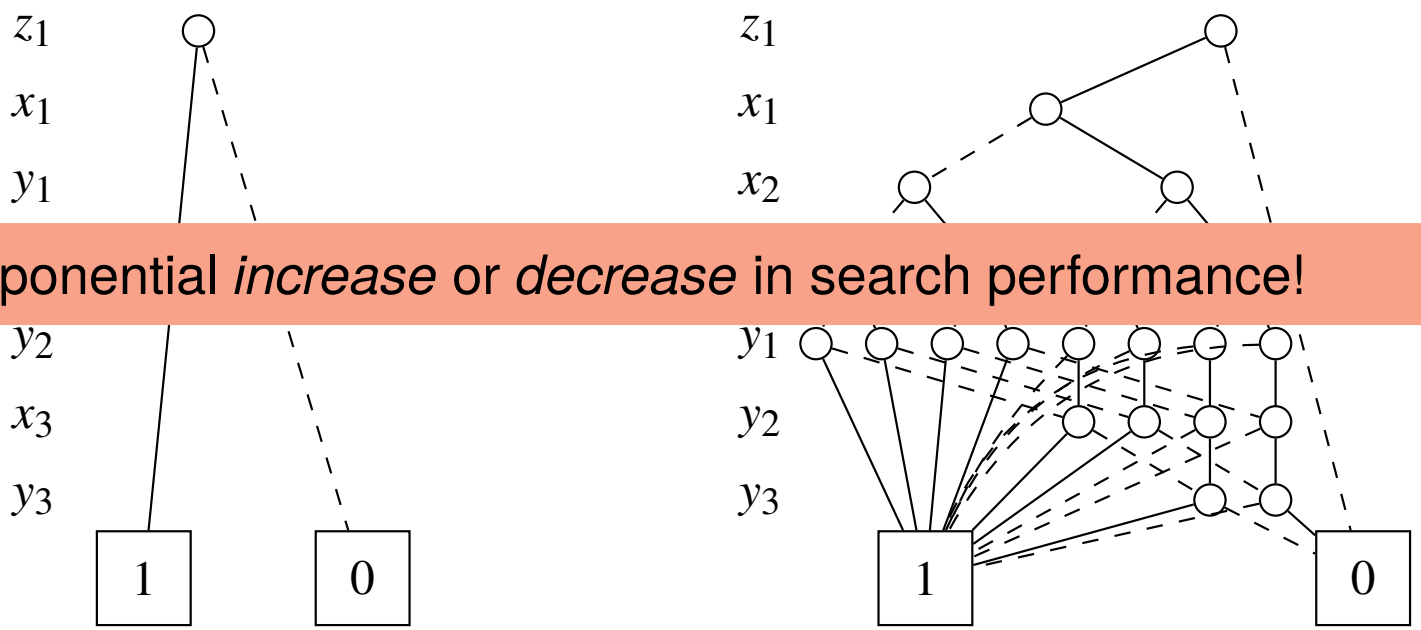
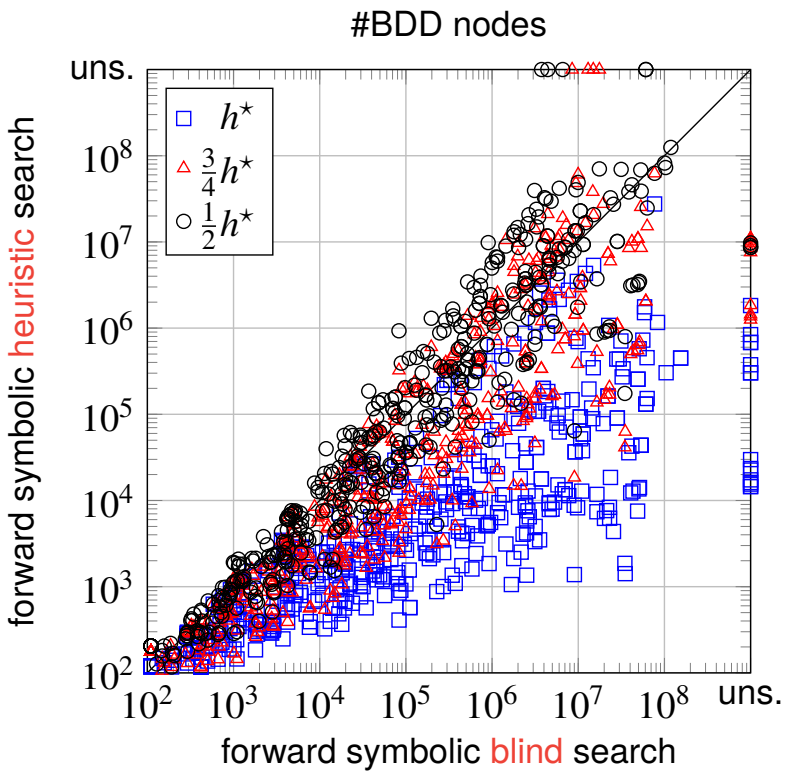


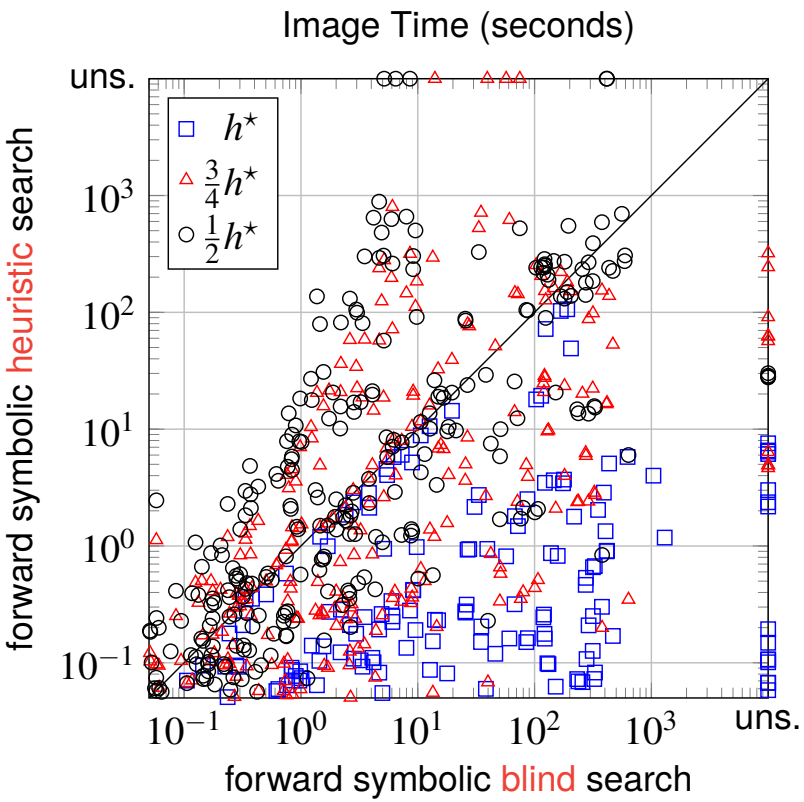
$\rightsquigarrow$ Exponential *increase* or *decrease* in search performance! □

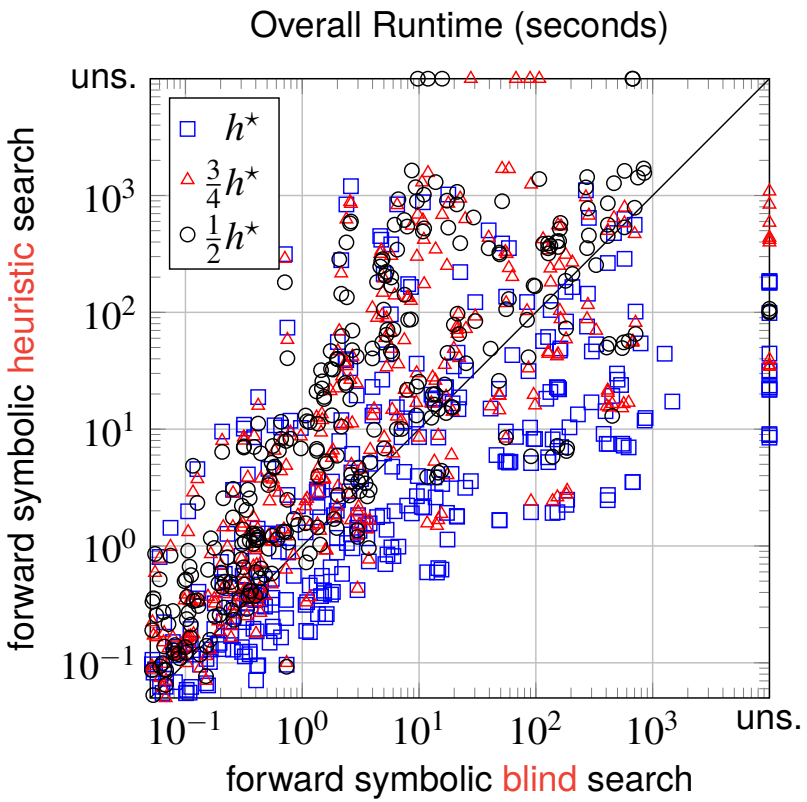
Empirical Results – BDD Sizes

- BDDA*
- Fraction perfect heuristics
  - $\rightsquigarrow c \cdot h^\star$
  - Precomputed
  - Multiple BDDs
- Domains from IPCs



Empirical Results – Runtime





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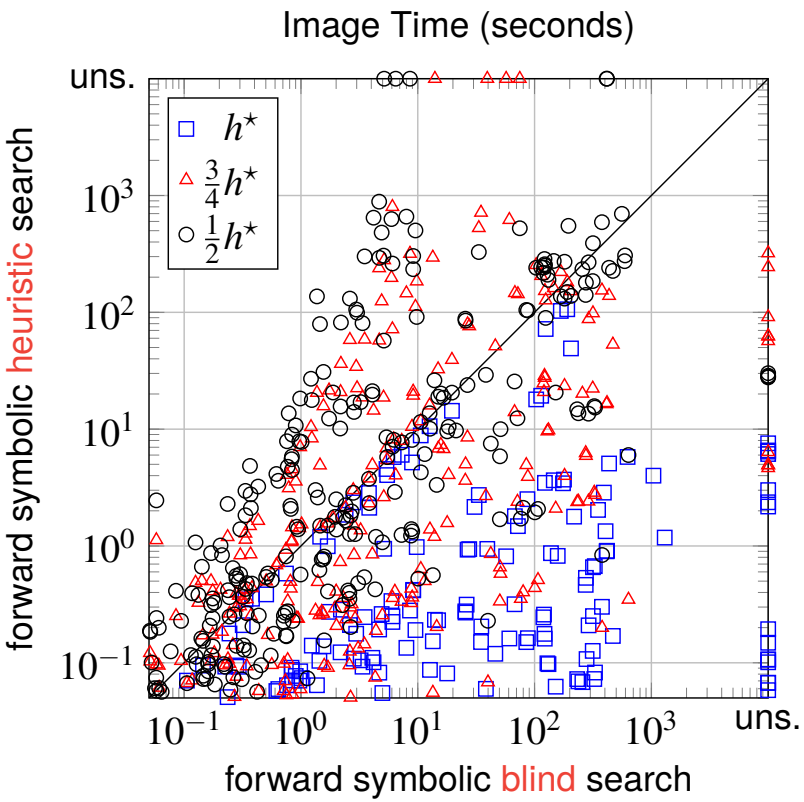

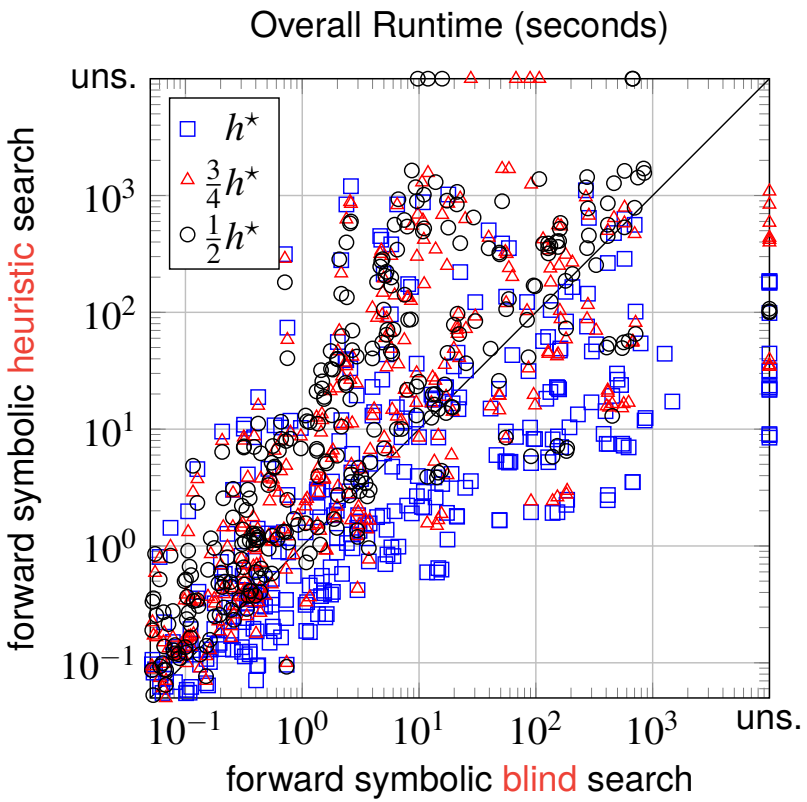

Similar results for symbolic bidirectional search.

Conclusion

- Heuristic computation and state evaluation are expensive [JVB08].
- BDDs can become exponentially larger by using heuristics.
  - Even with the perfect heuristics $h^\star$
- Overall target: small BDDs
- Fewer States $\not\Longrightarrow$ smaller BDDs
- Similar results for uni- and bidirectional search
- $\rightsquigarrow$ Heuristics do not pay off in general!

References I

Rune M. Jensen, Manuela M. Veloso, and Randal E. Bryant, *State-set branching: Leveraging BDDs for heuristic search*, AIJ **172** (2008), no. 2-3, 103–139.