

# Diverse and Additive Cartesian Abstraction Heuristics

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## Setting:

- Cost-optimal classical planning
- Admissible heuristic for  $A^*$

# Overview

- Single Cartesian abstraction
- Additive abstractions
- Diversification strategies

# CEGAR

# Counter-example guided abstraction refinement (CEGAR)

## CEGAR algorithm

Start with coarsest abstraction

Until concrete solution is found or time runs out:

- Find abstract solution
- Check if and why it fails in the real world
- Refine abstraction

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Drawbacks:

- Diminishing returns
- Goal facts are considered one after another

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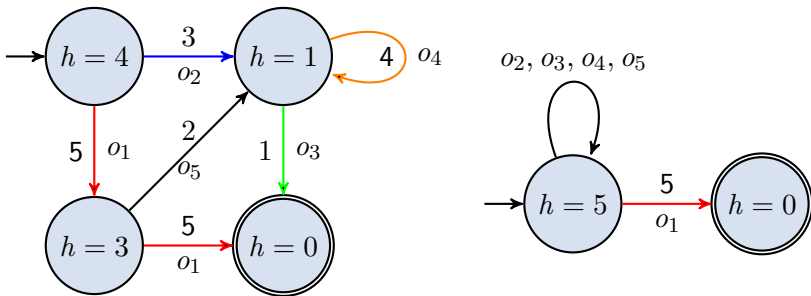
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→ Multiple abstractions

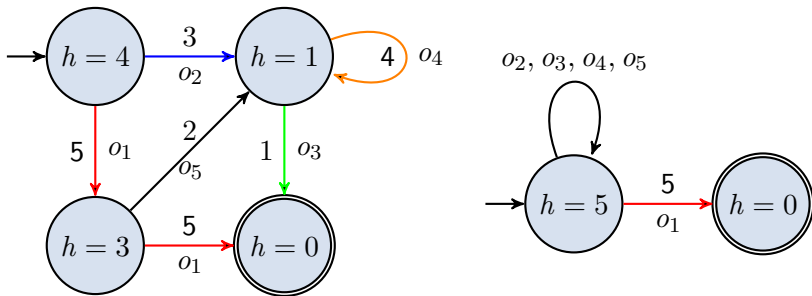
# Additive abstractions



# Multiple abstractions



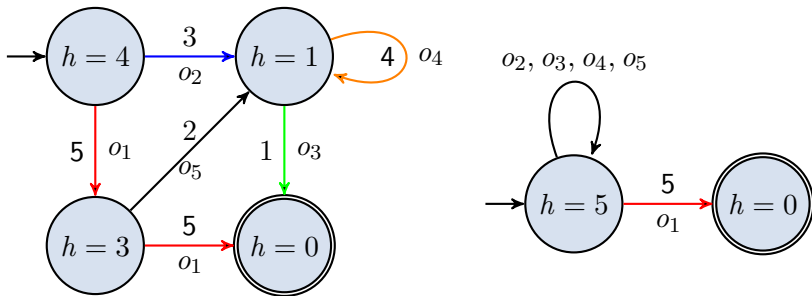
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How to combine heuristic estimates?

- Maximum:  $h(s_0) = \max(4, 5) = 5$

# Multiple abstractions

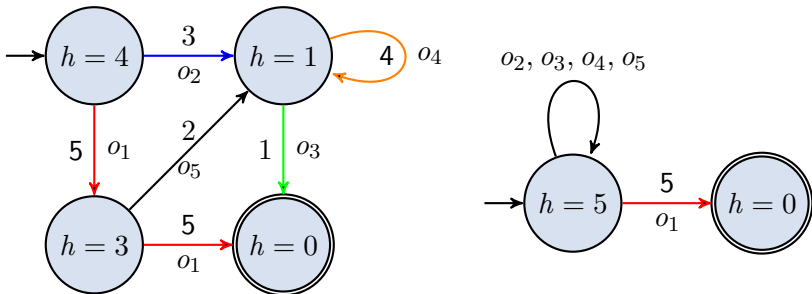


How to combine heuristic estimates?

- Maximum:  $h(s_0) = \max(4, 5) = 5$
- Cost partitioning:  $h(s_0) = 0 + 5 = 5$

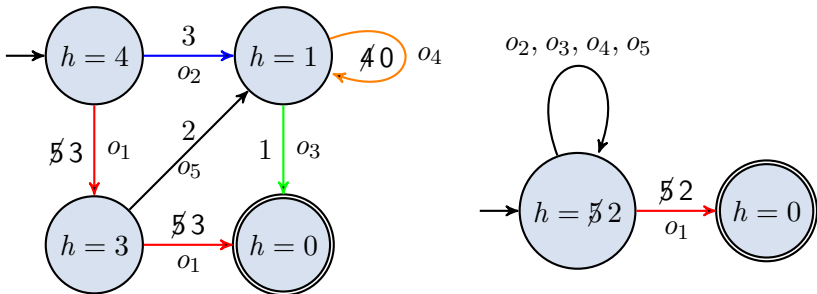
# Saturated cost partitioning

- Saturated cost function



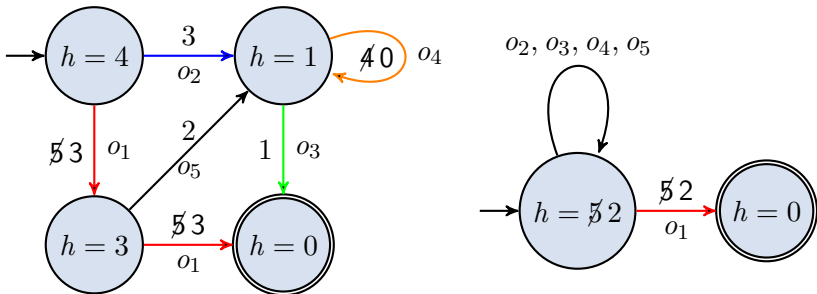
# Saturated cost partitioning

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- $h(s_0) = 4 + 2 = 6$

# Additive CEGAR abstractions

- Build  $n$  abstractions
- No changes to the CEGAR algorithm

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## Results

	Abstractions					
Coverage	1	2	5	10	20	50
<b>Sum (1396)</b>	562	559	564	<b>566</b>	<b>566</b>	562

# Diversification strategies

# Abstraction by goals

- Build an abstraction for each goal fact
- Focus on different subproblems
- **Problem:** tasks with single goal fact

# Abstraction by landmarks

- Compute fact landmarks
- Build an abstraction for each fact landmark  $l$
- **Problem:** landmarks as goals not admissible
- **Solution:**  $h_l(s) = 0$  if  $l$  might have been achieved
- Path-dependent landmark heuristics  $\rightarrow$  state-based criterion

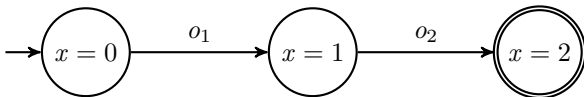
# Abstraction by landmarks

Modified task for landmark  $l$ :

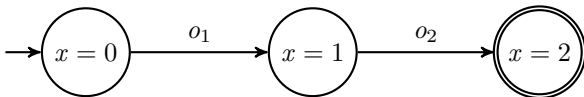
- Compute *possibly-before* set  $pb(l)$
- Facts:  $pb(l) \cup \{l\}$
- Goal:  $l$
- Operators:
  - discard operators with preconditions not in  $pb(l)$
  - let operators achieving  $l$  achieve **only**  $l$
- Initial state: unmodified

$$h_l(s) = 0 \text{ if } s \notin pb(l) \cup \{l\}$$

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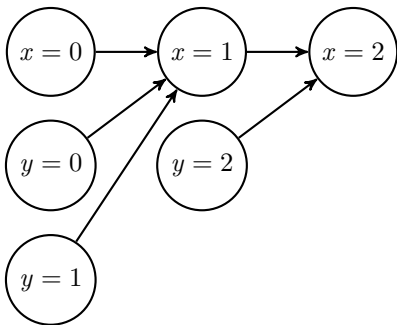


## Solution:

- Compute landmark orderings
- Combine facts that have probably already been achieved

# Abstraction by landmarks: improved

## Example

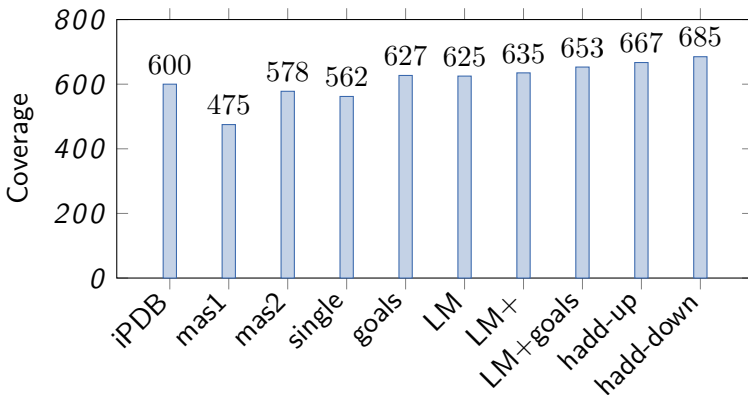


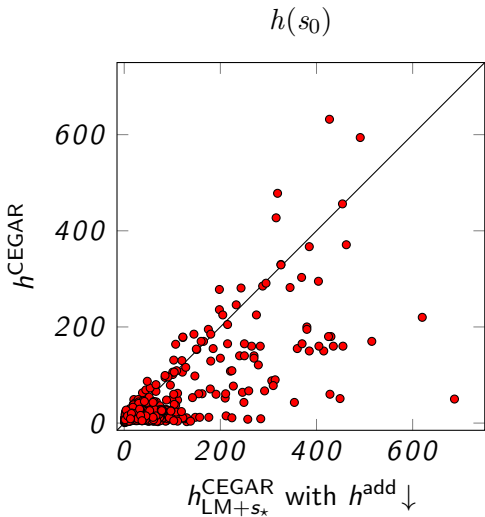
- $x = 1$ :  $\{y = 0, y = 1\}$
- $x = 2$ :  $\{y = 0, y = 1, y = 2\}, \{x = 0, x = 1\}$



# Experiments

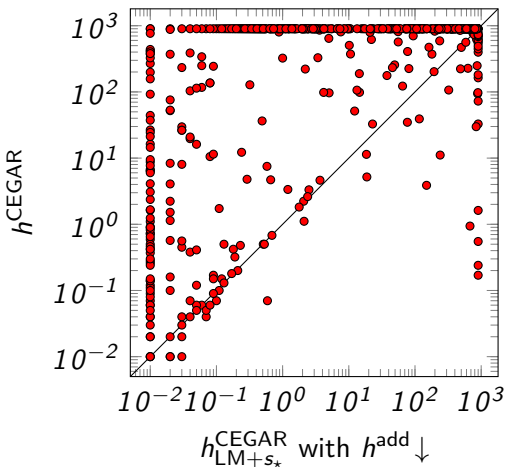
# Comparison to other abstraction heuristics



$h^{\text{CEGAR}}$  vs.  $h_{\text{LM}+s_*}^{\text{CEGAR}}$ 

$h^{\text{CEGAR}}$  vs.  $h_{\text{LM}+s_*}^{\text{CEGAR}}$ 

Time for Computing Abstractions (secs)



# Conclusion

# Future work

- Investigate impact of fact ordering
- Use saturated cost partitioning for other abstraction heuristics

# Summary

- New cost partitioning algorithm
- Several diversification strategies
- Competitive performance