On the Relationship Between State-Dependent Action Costs and Conditional Effects in Planning

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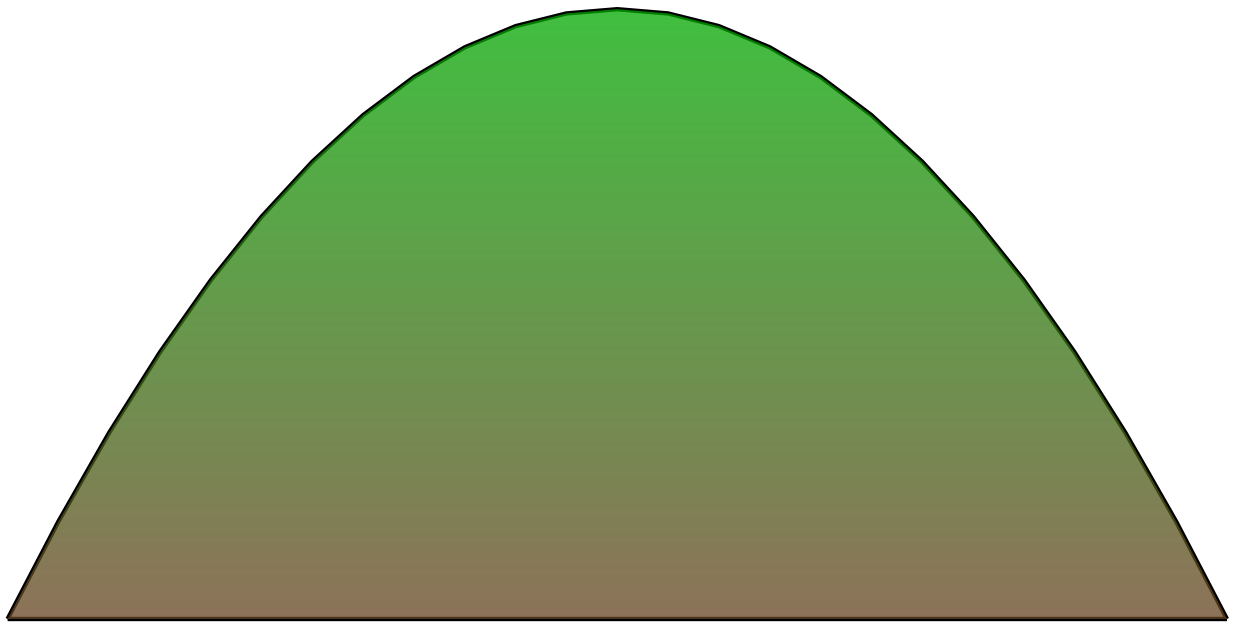
Relaxations with State-Dependent Costs and Effects



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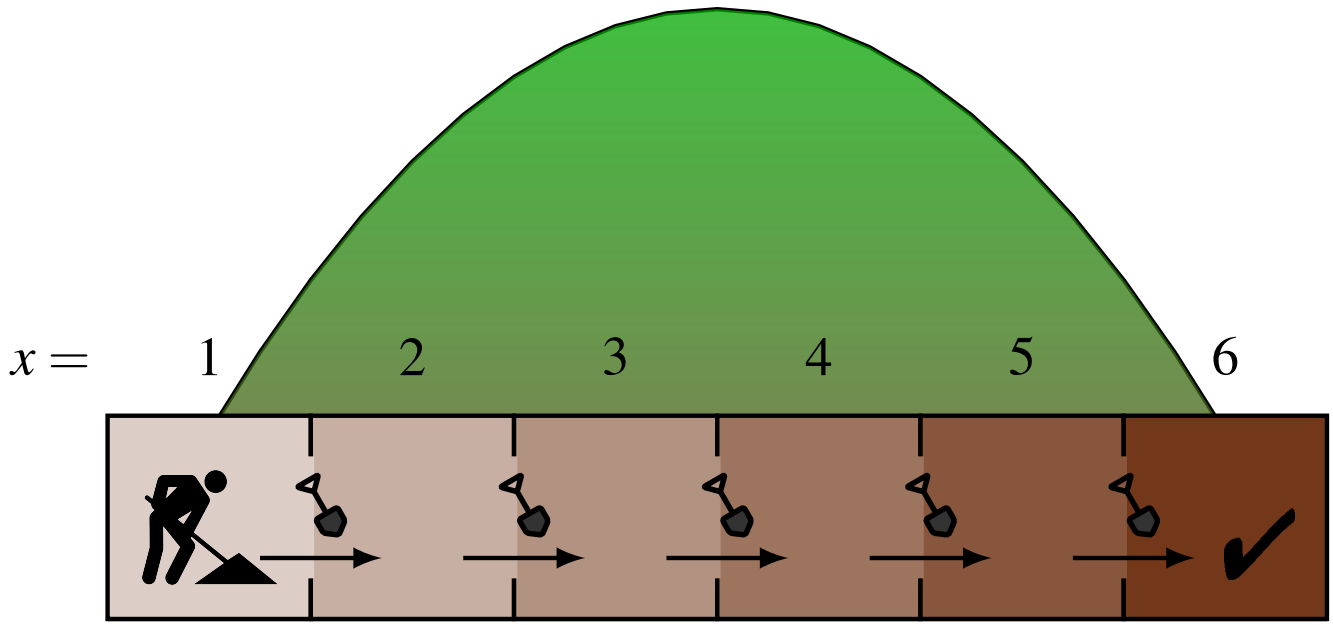
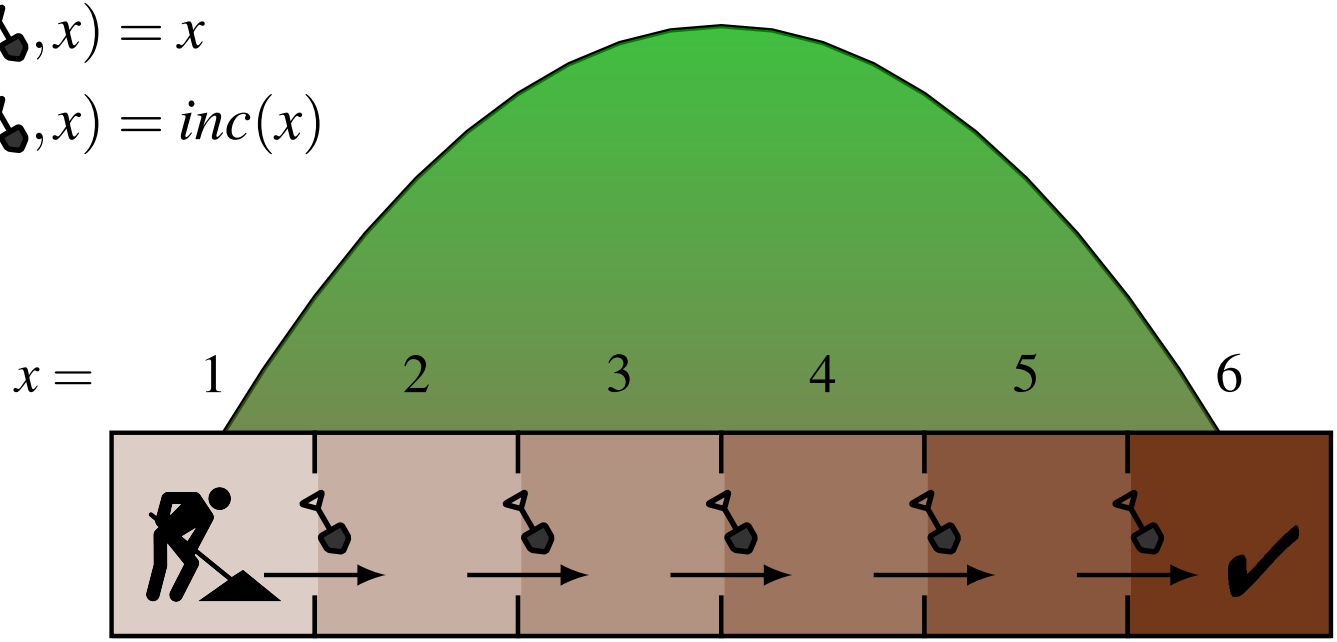


Relaxations with State-Dependent Costs and Effects

$cost(\text{shovel}, x) = x$

$eff(\text{shovel}, x) = inc(x)$



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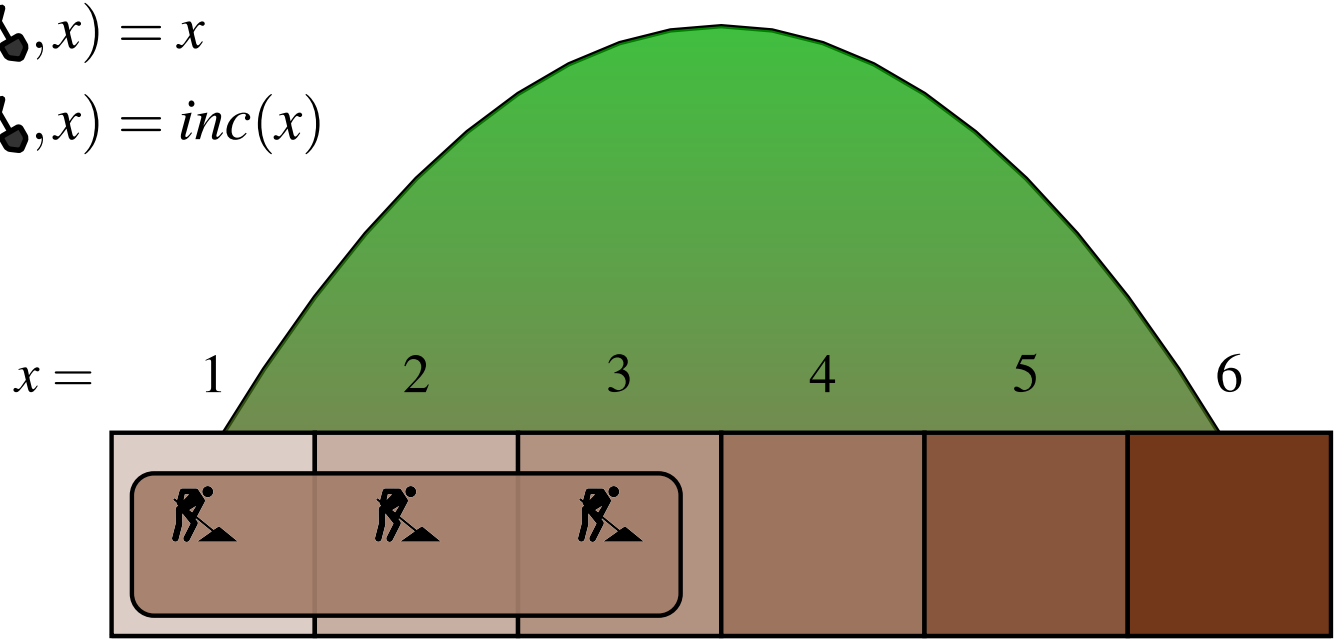

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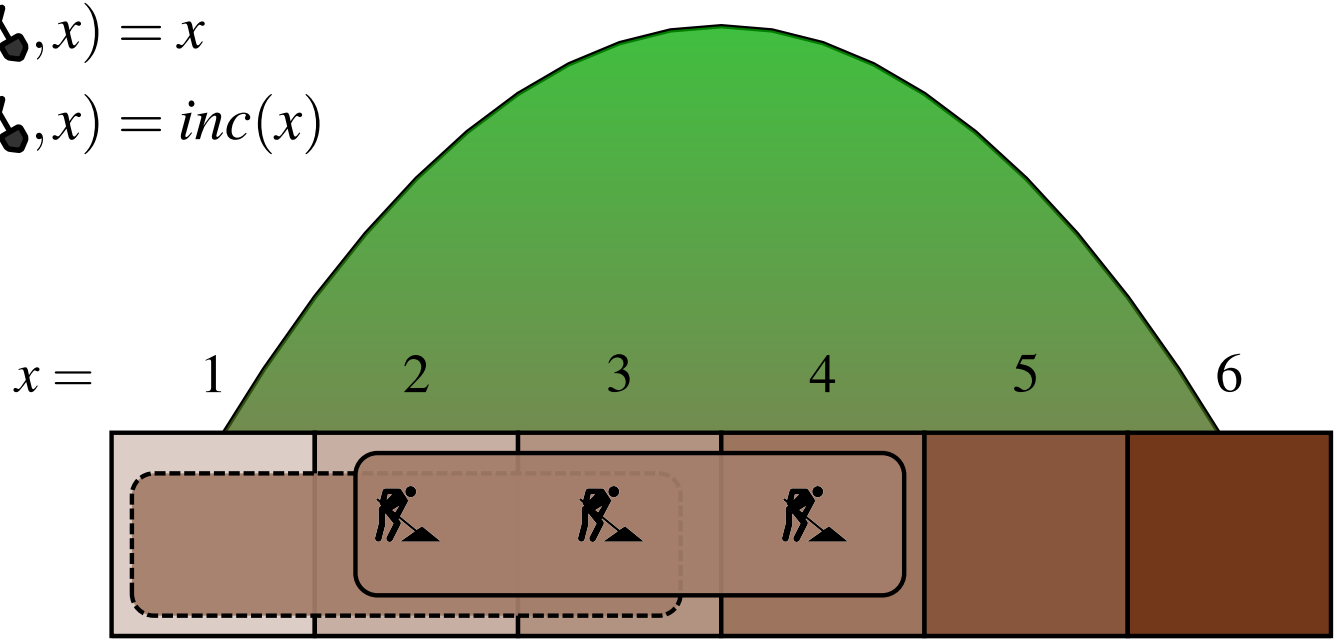

$x^+ = \{1, 2, 3\}$

$cost(\text{shovel}, x^+) = 1 \quad (\min)$

$eff(\text{shovel}, x^+) = \{2, 3, 4\} \quad (\bigcup)$

Relaxations with State-Dependent Costs and Effects

$cost(\text{⛏}, x) = x$

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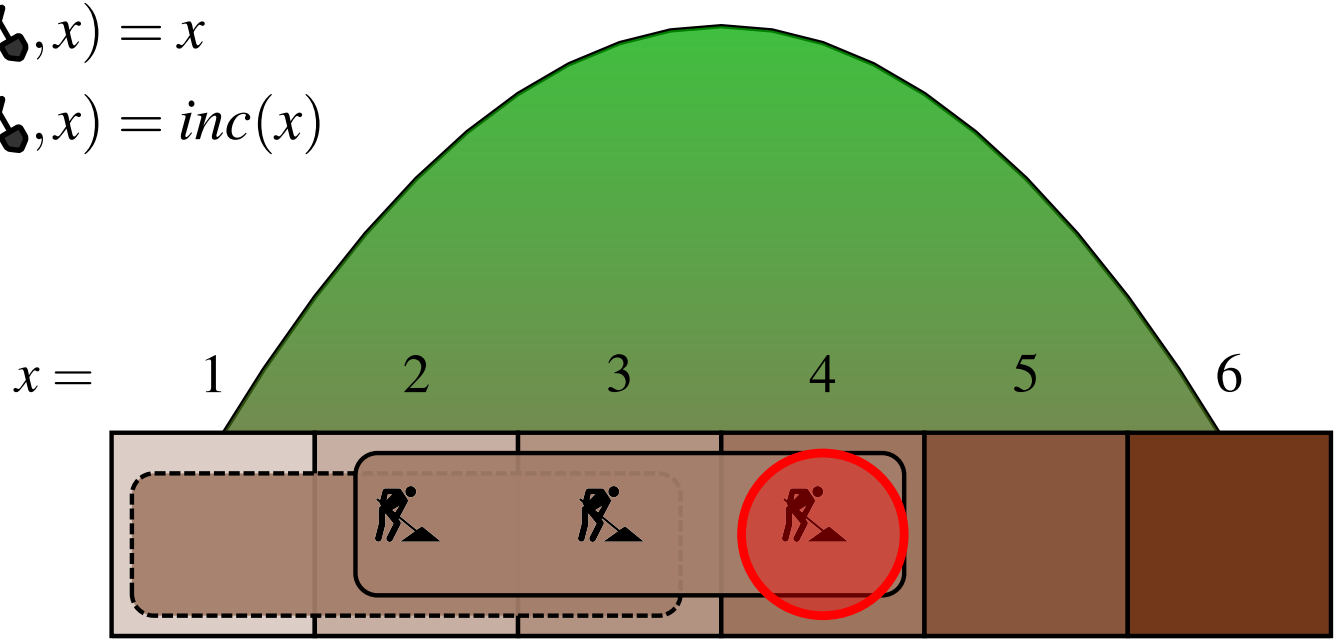

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Relaxations with State-Dependent Costs and Effects

What happened?

- Cost-effect mismatch!
- $\rightsquigarrow$ Uninformative heuristic $h^+(x_1) = 5$ vs. $h^*(x_1) = 15$

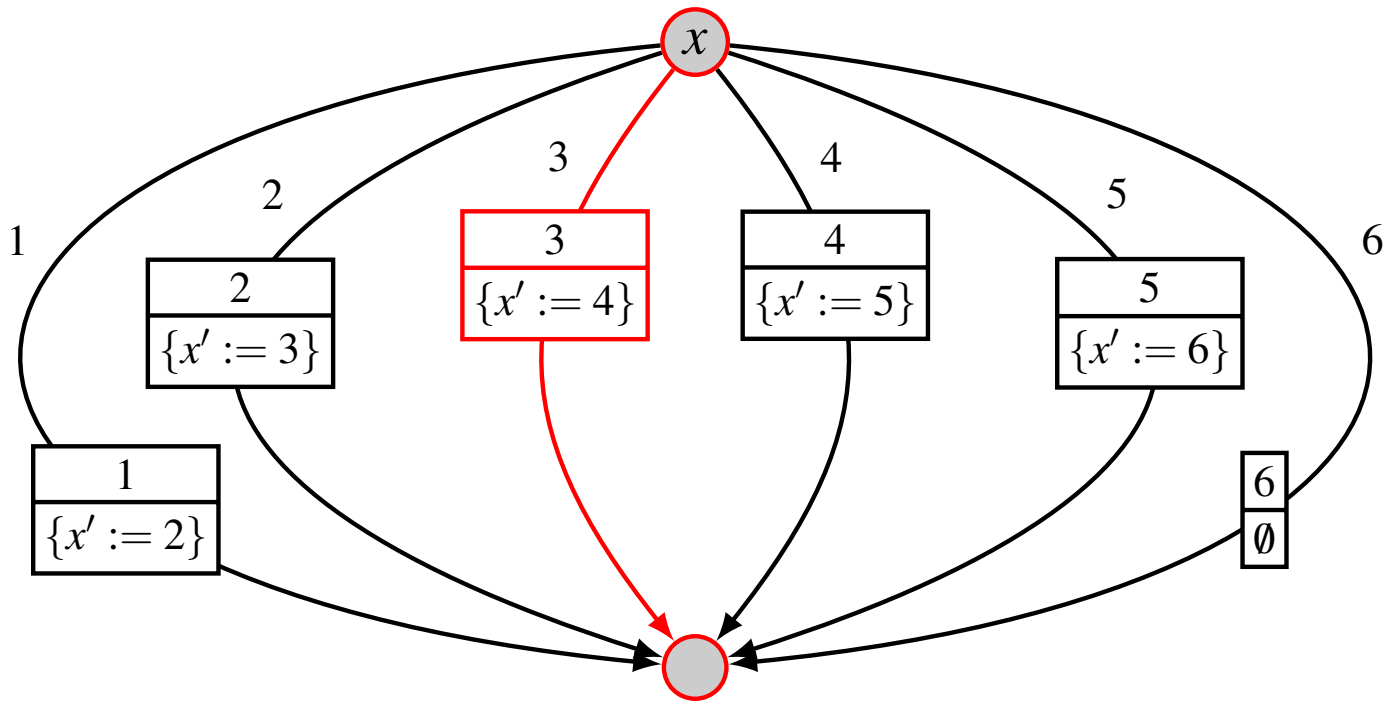
What to do about it?

- Handle costs and effects in combination!
- How?
  - ✗ in tabular form? Exponential blow-up.
  - ✓ as decision diagram? Often compact.

  $\rightsquigarrow$ edge-valued multi-valued decision diagrams (EVMDDs)
  [Ciardo and Siminiceanu 2002; Lai, Pedram, and Vrudhula 1996]

Combined Representation using EVMDDs

Combined EVMDD for costs and effects



Consequence: effect $x' := 4$ now associated with cost 3.

EVMDD Construction

How to construct those EVMDDs?

Possible approach:

- Repeated application of apply procedure
  [Ciardo and Siminiceanu 2002; Lai, Pedram, and Vrudhula 1996]

Prerequisite:

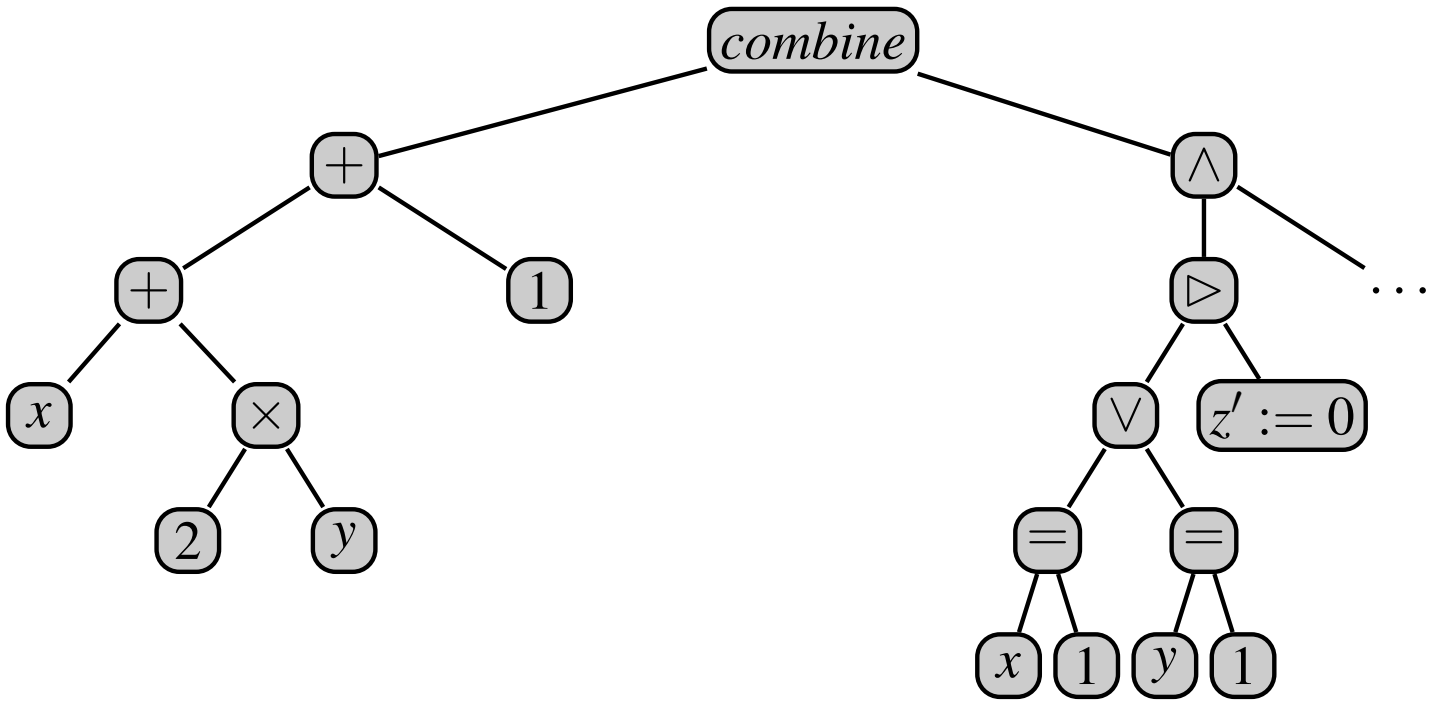
✔ Generalize *apply* procedure beyond numbers.

Recursive construction:

- Build ASTs of normalized cost and effects, and their combination.
- Recursively run *apply* procedure on this AST.

EVMDD Construction

Example: cost $x + 2y + 1$ combined with effect $((x \vee y) \rhd \neg z') \wedge \ldots$



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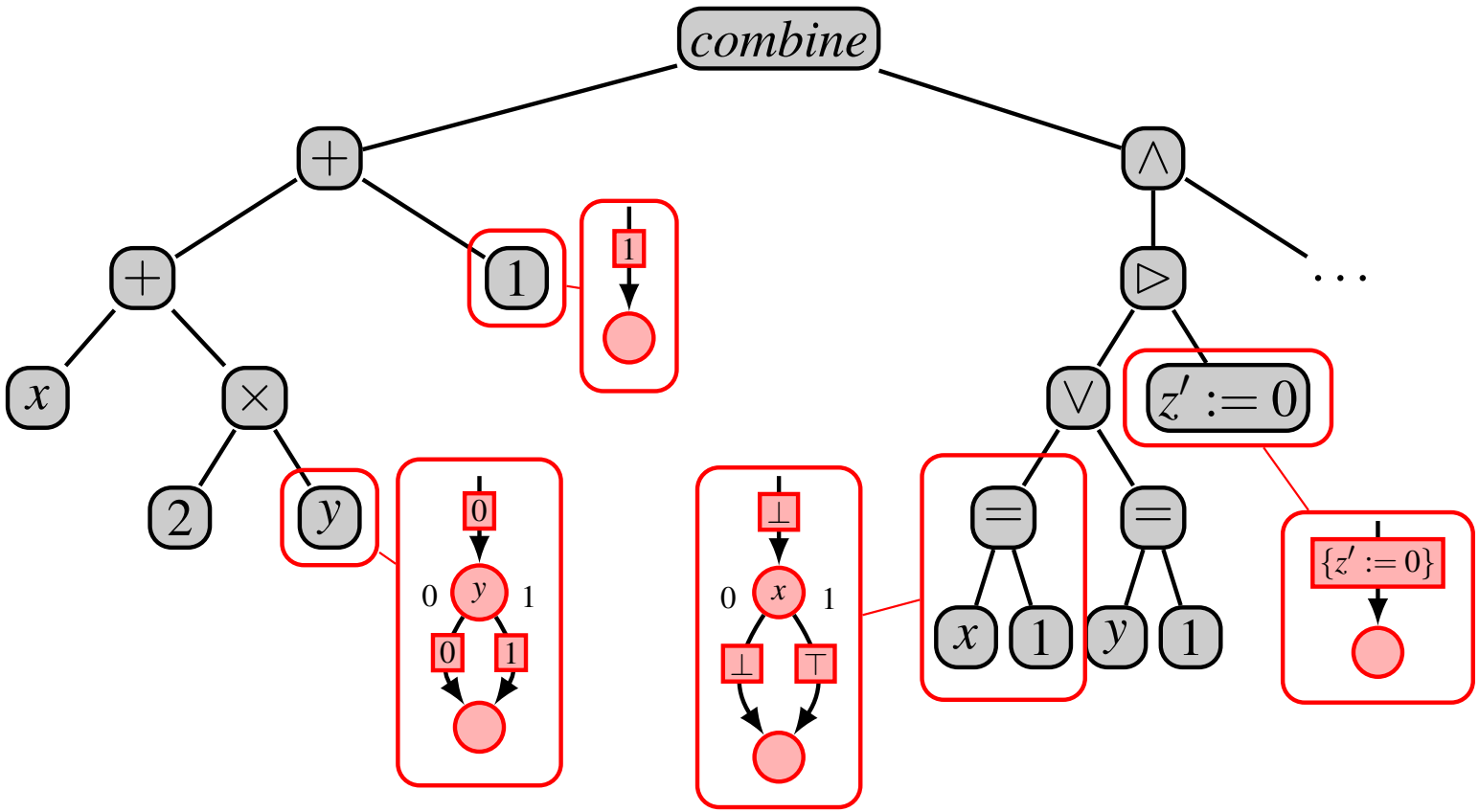

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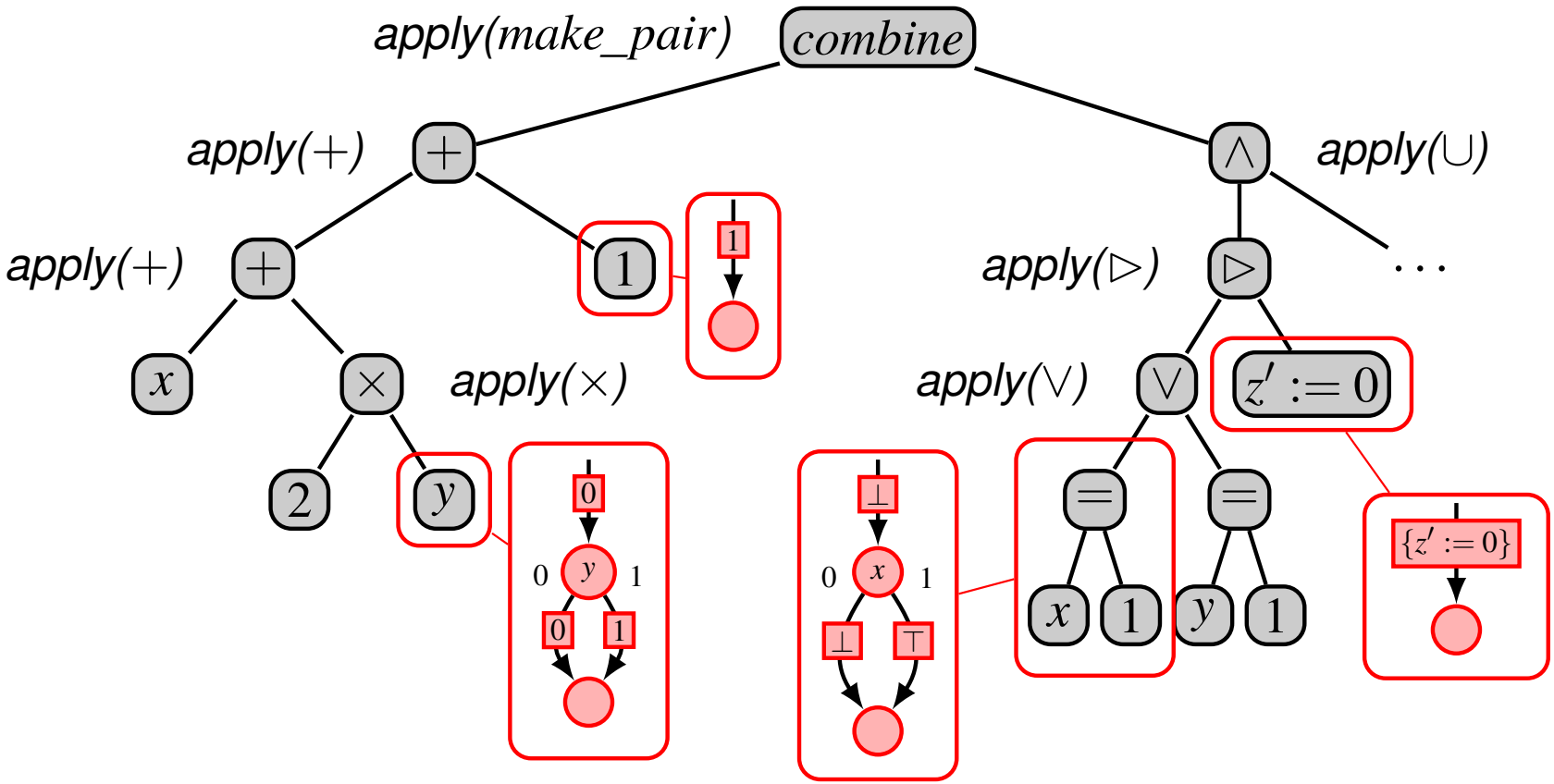

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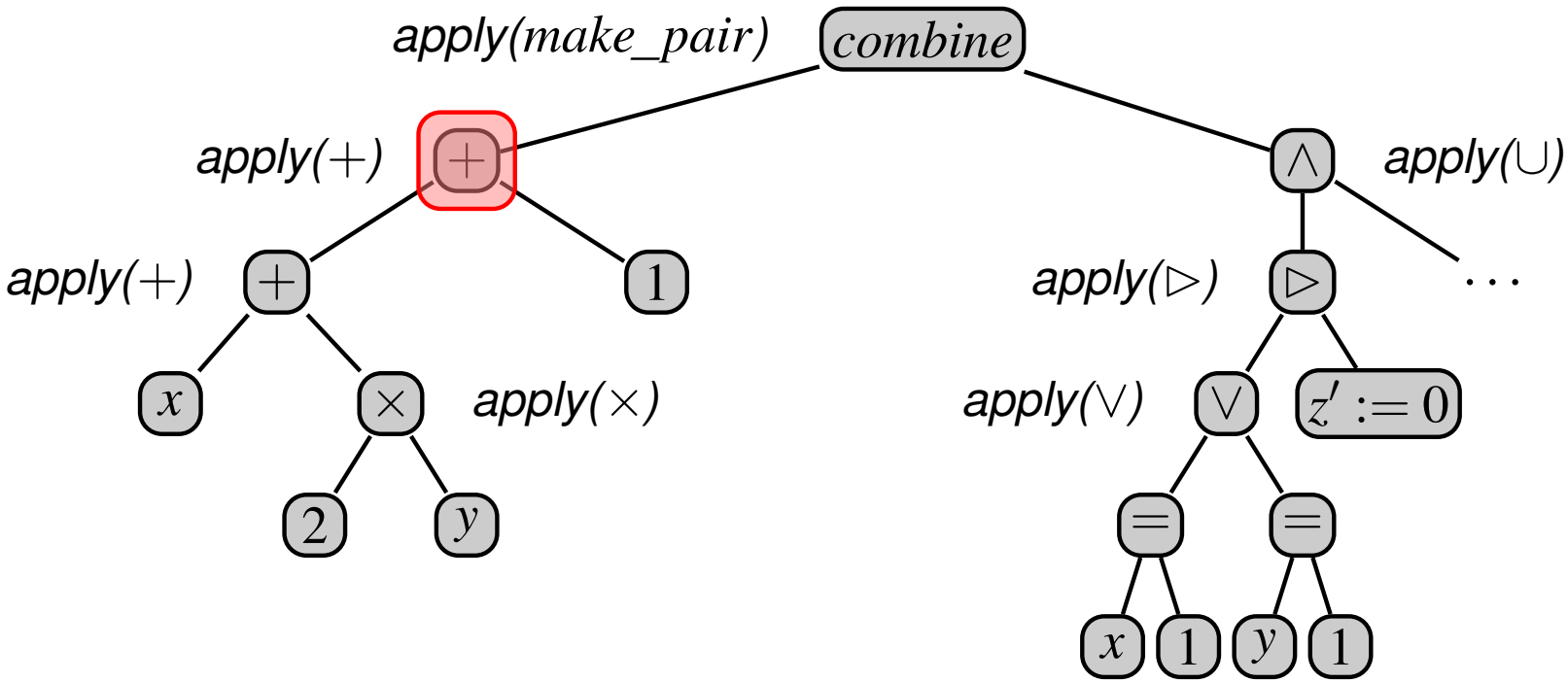
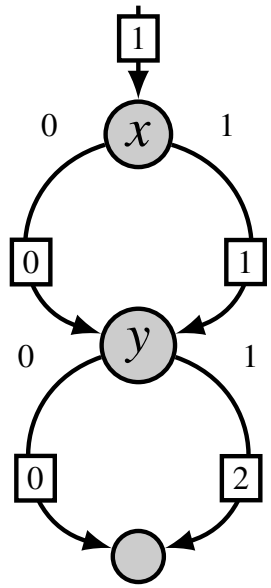


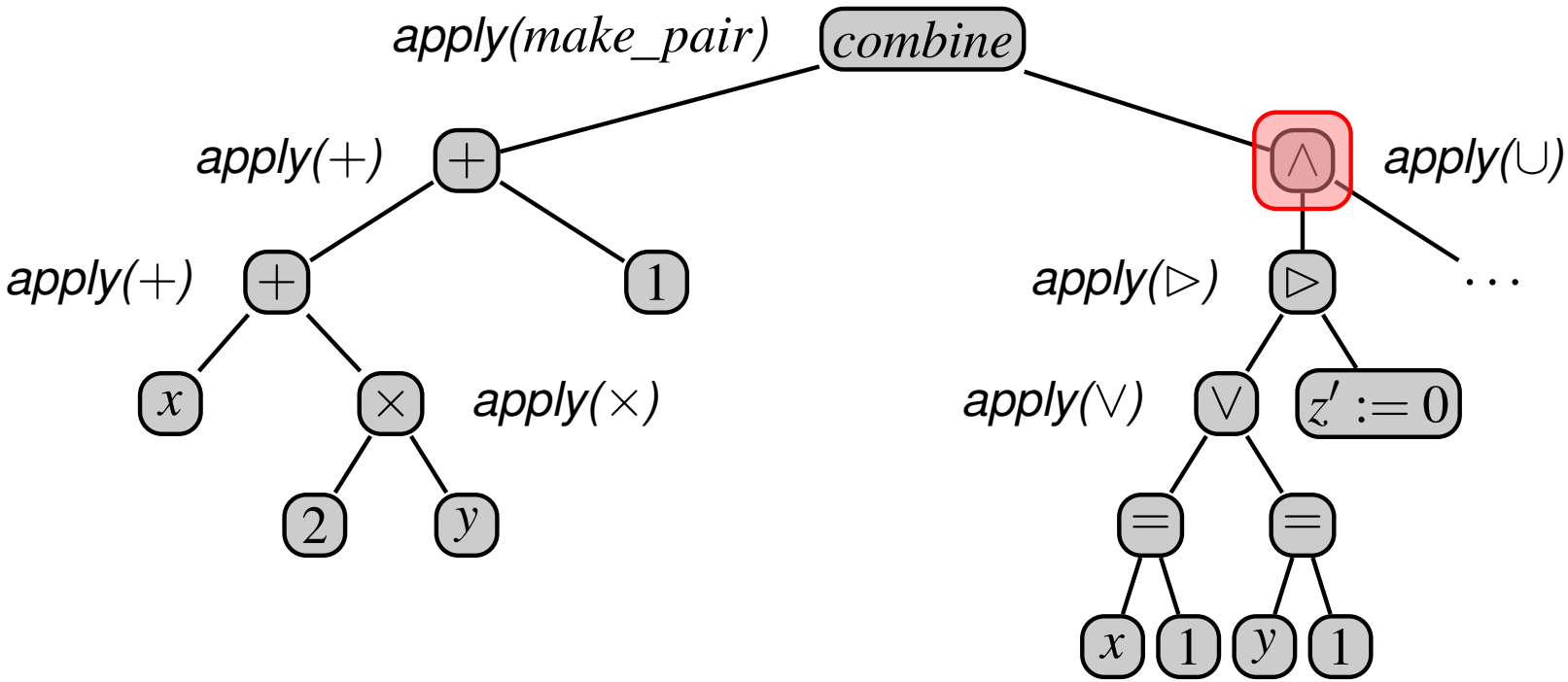
EVMDD Construction

Example: cost



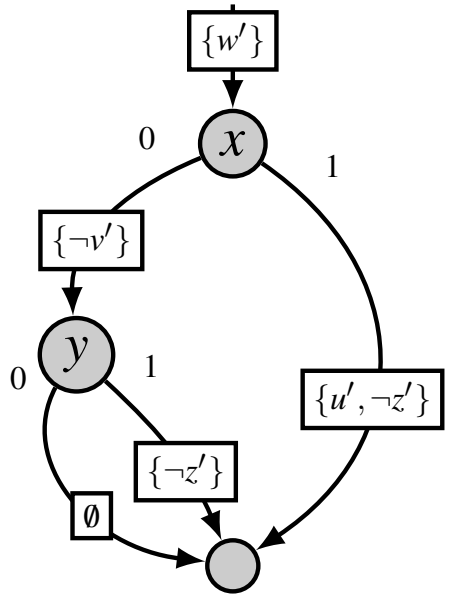
EVMDD Construction

Example: cost $x + 2y + 1$ combined with effect $((x \vee y) \rhd \neg z') \wedge \ldots$



EVMDD Construction

Example: effects



EVMDD Construction

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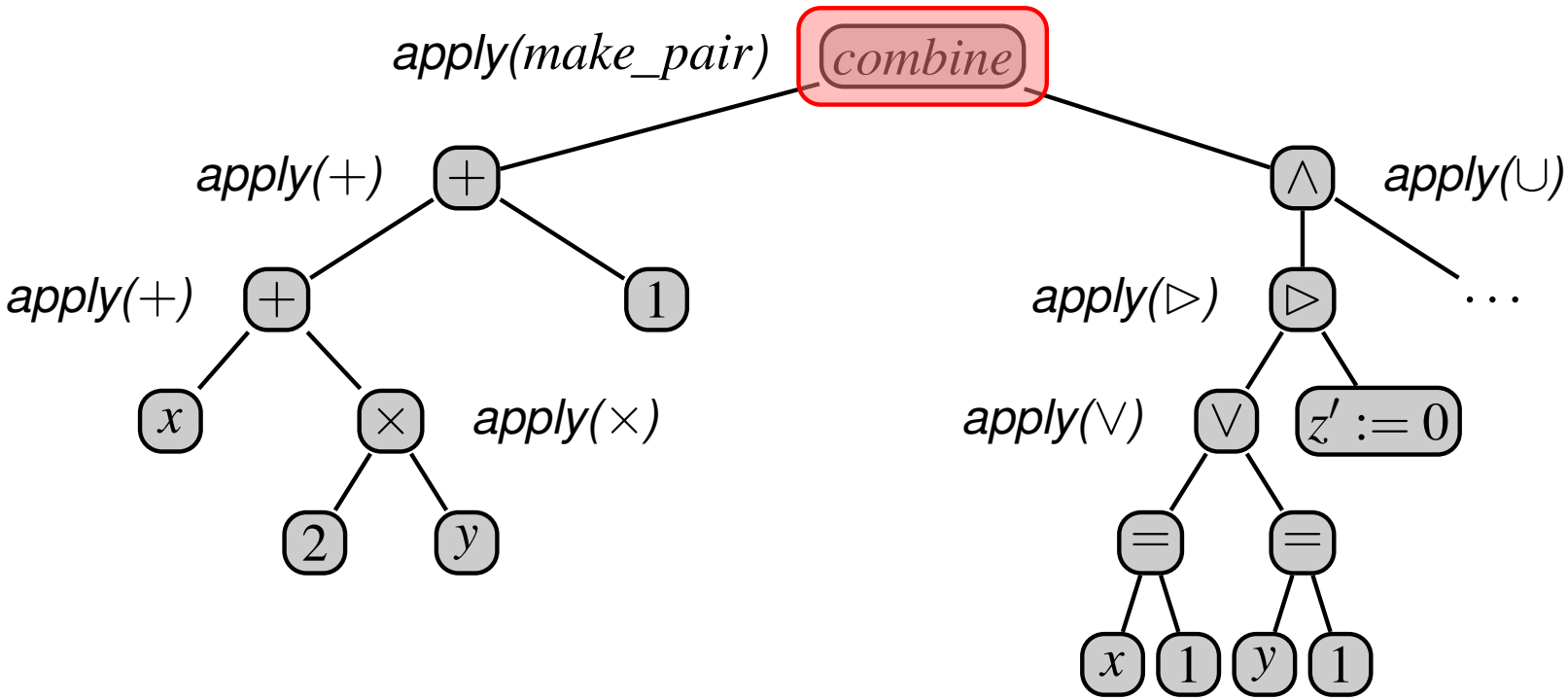
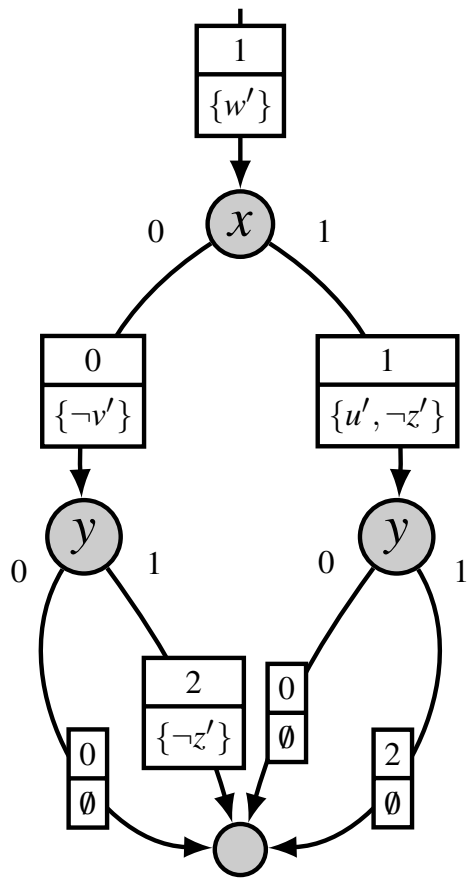


EVMDD Construction

Example: cost and effect combined



Properties of the Construction

Proposition

If EVMDD $\mathcal{E}_i$ represents function f_i $(i = 1, 2)$,
then EVMDD $apply(\circ, \mathcal{E}_1, \mathcal{E}_2)$ represents $f(s) = f_1(s) \circ f_2(s)$. □

E. g., $\circ = +, -, \vee, \wedge, \triangleright, make\_pair, \ldots$

Properties of the Construction

Corollary

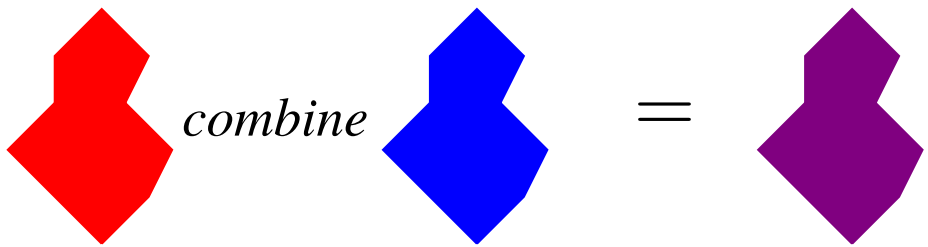
Combined cost-effect EVMDD represents function f with

$$f(s) = (\text{cost in } s,\ \text{active effects in } s)\ .$$

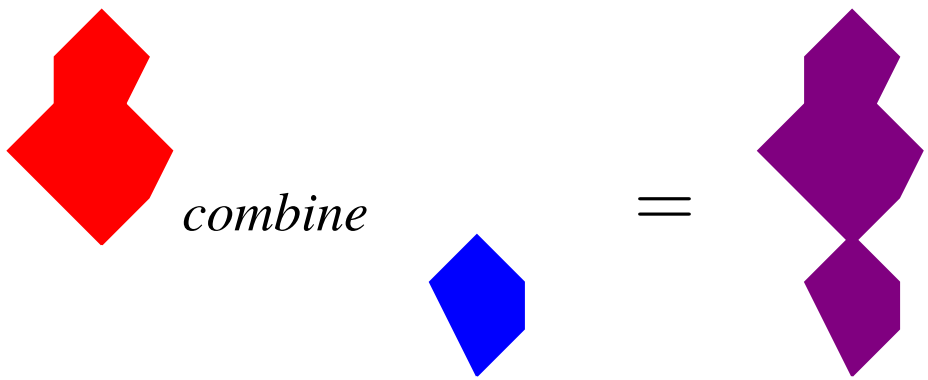
Properties of the Construction

Size of combined cost-effect EVMDD:

- worst case: product of factor sizes
- best cases: $\max/\sum$ of factor sizes if
  - factors have identical structure:



  - or factors depend on disjoint variable sets:



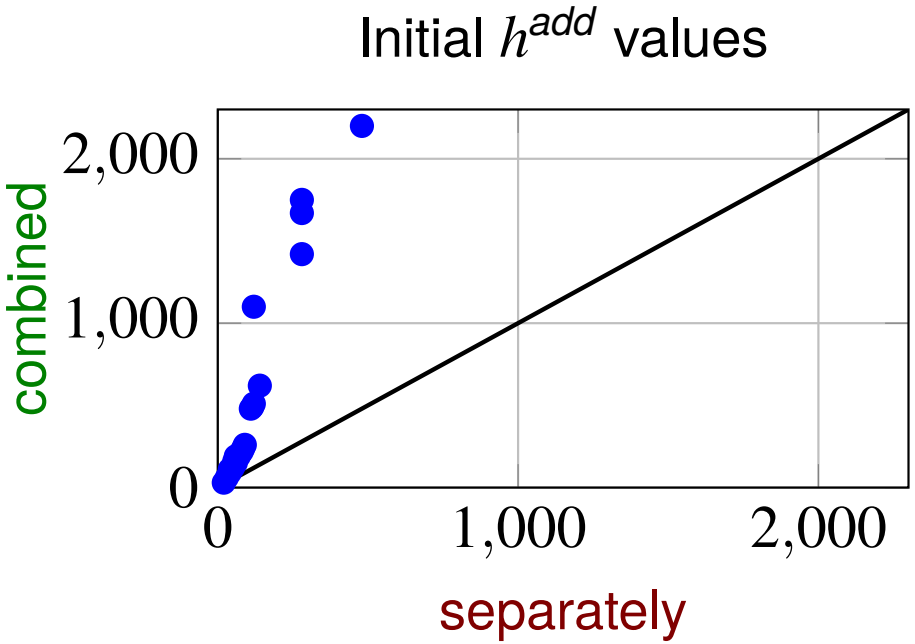
Uses of Cost-Effect EVMDDs

- Efficient computation of relaxed semantics
- Heuristics based on that: $h^+(x_1) = 15$!
- Compiling away state-dependent costs and effects

Empirical Results

Preliminary. Cost-based navigation domain.

- Heuristic values: costs and effects combined vs. separately



- Representation size of combination: (small instances, on avg)
  - EVMDD-based: 58 nodes
  - tabular: 1381 entries

Summary

- Informative heuristics wanted
  $\rightsquigarrow$ combined treatment of state-dependent costs and effects
- Representation: cost and effect EVMDDs
- Construction: repeated *apply*