From Non-Negative to General Operator Cost Partitioning

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January 29, 2015

Introduction

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State space search

- Common approach: A^* with admissible heuristic
- One heuristic often not sufficient
- How to combine heuristics?

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  - Sum? Not admissible
  - Maximum? Does not use all information

Breakthrough: Cost partitioning

- Make arbitrary heuristics additive
- Part of many state-of-the-art heuristics

Operator Cost Partitioning

Main idea

- Create copies of the original problem
- Distribute operator cost function between copies
- Compute one heuristic per copy
- Sum resulting heuristic values

Operator Cost Partitioning

Operator Cost Partitioning [Katz and Domshlak 2010]

Find cost functions $c_1, \ldots, c_n$ with

- Non-negative costs: $c_i \geq 0$
- Costs are distributed: $\sum_i c_i \leq$ original cost

$\Rightarrow$ Admissible estimates using cost function c_i are additive

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Why restrict costs to non-negative values?

General Operator Cost Partitioning

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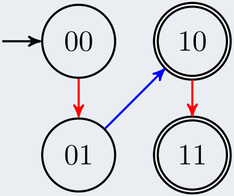
General Cost Partitioning Example

Example



General Cost Partitioning Example

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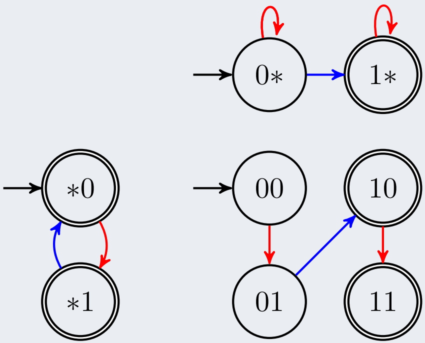

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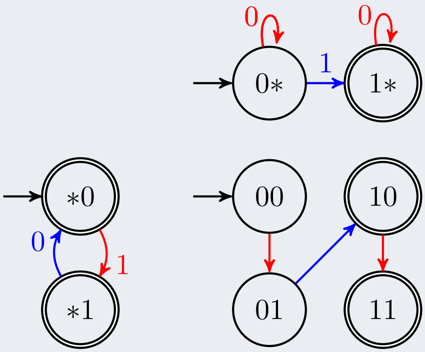
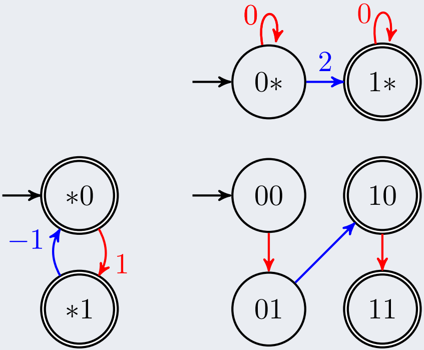


Heuristic value: $0 + 1 = 1$

General Cost Partitioning Example

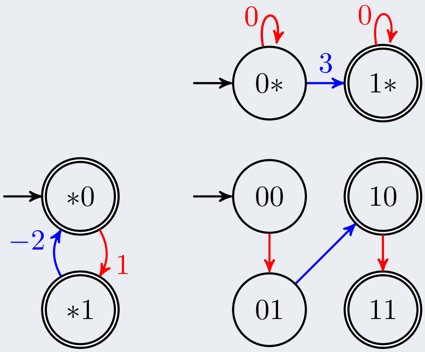
Example



Heuristic value: $0 + 2 = 2$

General Cost Partitioning Example

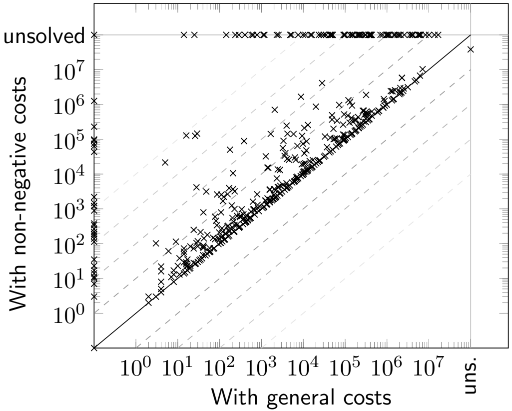
Example



Heuristic value: $-\infty + 3 = -\infty$

Heuristic Quality of General Cost Partitioning

Expansions for optimal cost partitioning of atomic projections



Relation to Other Topics in Heuristic Search Planning

General Operator Cost Partitioning in Relation to ...

- Operator-counting heuristics
- State equation heuristic
- A new approach to heuristic construction (potential heuristics)

1) Operator-Counting Heuristics

Operator-counting heuristics [Pommerening et al. 2014]

- Minimize total plan cost
- Subject to necessary properties of any plan (constraints)

Different sets of constraints define different heuristics

1) Operator-Counting Heuristics: Theoretical Result

Theorem

Combining operator-counting heuristics in one LP
is equivalent to
computing their optimal general cost partitioning.

2) State Equation Heuristic

Special case: state equation heuristic [van den Briel et al. 2007, Bonet 2013]

- Categorization previously unclear
    - Landmarks?
    - Abstractions?
    - Delete relaxations?
    - Critical paths?

2) State Equation Heuristic

Special case: state equation heuristic [van den Briel et al. 2007, Bonet 2013]

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Theorem

State equation heuristic

=

Optimal general cost partitioning of all atomic projection heuristics

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  - ~~Landmarks?~~
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Theorem

State equation heuristic

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Optimal general cost partitioning of all atomic projection heuristics

3) Potential Heuristics

Potentials

- Numerical value associated with each fact
- Heuristic value is sum of potentials for facts in state

Image credit: David Lapetina

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Linear constraints over potentials

- Express consistency and admissibility
- Necessary and sufficient conditions

Image credit: David Lapetina

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- Numerical value associated with each fact
- Heuristic value is sum of potentials for facts in state

Linear constraints over potentials

- Express consistency and admissibility
- Necessary and sufficient conditions

Optimization criterion

- Can optimize any function over potentials
- Here: maximize heuristic value of a state

Image credit: David Lapetina

3) Potential Heuristics: Theoretical Result

Theorem

Potential heuristic optimized in each state

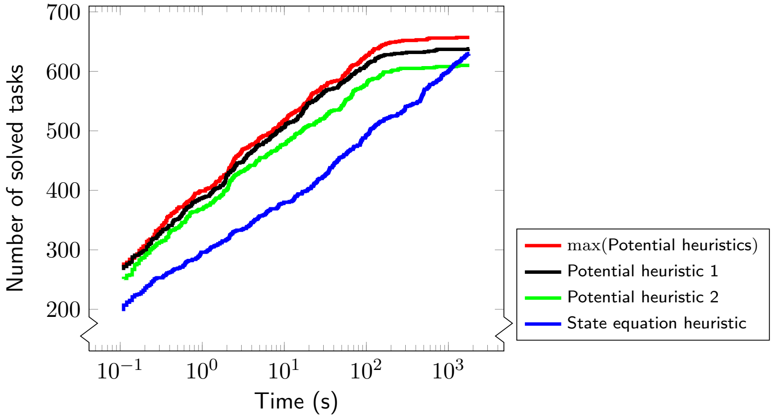
=

State equation heuristic

Optimizing potentials less frequently

- Trade off accuracy for evaluation speed
- Here: optimize once for heuristic value of initial state

3) Potential Heuristics: Practice



Take Home Messages

Heuristic combination

Operator counting

$\simeq$

Optimal general cost partitioning

Equivalent heuristics

State equation heuristic

$=$

Optimal general cost partitioning of atomic projections

$=$

Potential heuristic (optimized in each state)

Interesting new heuristic family: potential heuristics

Potential Heuristics (Details)

Potential heuristic

$$\text{Maximize } f(\mathit{Potentials}) \text{ subject to}$$

$$\sum_{V} \mathit{Potential}_{\mathit{goal}[V]} \leq 0$$

$$\sum_{V} (\mathit{Potential}_{\mathit{pre}(o)[V]} - \mathit{Potential}_{\mathit{eff}(o)[V]}) \leq \mathit{cost}(o) \quad \text{for each } o \in O$$

Heuristic properties

- Admissibility: $h(s) \leq h^*(s)$ for all states s
- Consistency: $h(s) \leq h(s') + c(o)$ for all transitions $s \xrightarrow{o} s'$
- Goal awareness: $h(s) \leq 0$ for all goal states s
- Goal awareness + consistency $\Leftrightarrow$ admissibility + consistency