

Planning and Optimization

D5. Potential Heuristics

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D5.1 Introduction

Introduction

- ▶ Operator-counting heuristics solve an LP to compute the heuristic estimate **for a single state**.
- ▶ Can we also define an **entire heuristic function** solving only one LP?
- ▶ **Axiomatic approach** for defining heuristics:
 - ▶ What should a heuristic look like mathematically?
 - ▶ Which properties should it have?
- ▶ Define a **space of interesting heuristics**.
- ▶ Use **optimization** to pick a good representative.

Potential Heuristics

Potential Heuristics: Idea

Heuristic design as an optimization problem:

- ▶ Define simple numerical **state features** f_1, \dots, f_n .
- ▶ Consider heuristics that are **linear combinations** of features:

$$h(s) = w_1 f_1(s) + \dots + w_n f_n(s)$$

with weights (**potentials**) $w_i \in \mathbb{R}$

- ▶ Find potentials for which h is admissible and well-informed.

Motivation:

- ▶ **declarative approach** to heuristic design
- ▶ heuristic **very fast to compute** if features are

D5.2 Potential Heuristics

Features

Definition (feature)

A (state) **feature** for a planning task is a numerical function defined on the states of the task: $f : S \rightarrow \mathbb{R}$.

Potential Heuristics

Definition (potential heuristic)

A **potential heuristic** for a set of features $\mathcal{F} = \{f_1, \dots, f_n\}$ is a heuristic function h defined as a **linear combination** of the features:

$$h(s) = w_1 f_1(s) + \dots + w_n f_n(s)$$

with weights (**potentials**) $w_i \in \mathbb{R}$.

↪ cf. **evaluation functions** for board games like chess

Atomic Potential Heuristics

Atomic features test if some atom is true in a state:

Definition (atomic feature)

Let $X = x$ be an atom of a FDR planning task.

The **atomic feature** $f_{X=x}$ is defined as:

$$f_{X=x}(s) = \begin{cases} 1 & \text{if variable } X \text{ has value } x \text{ in state } s \\ 0 & \text{otherwise} \end{cases}$$

- ▶ We only consider **atomic** potential heuristics, which are based on the set of all atomic features.
- ▶ **Example** for a task with state variables X and Y :

$$h(s) = 3f_{X=a} + \frac{1}{2}f_{X=b} - 2f_{X=c} + \frac{5}{2}f_{Y=d}$$

D5.3 Finding Good Potential Heuristics

How to Set the Weights?

We want to find **good** atomic potential heuristics:

- ▶ admissible
- ▶ consistent
- ▶ well-informed

How to achieve this? **Linear programming to the rescue!**

Admissible and Consistent Potential Heuristics

Constraints on potentials **characterize** (= are necessary and sufficient for) admissible and consistent atomic potential heuristics:

Goal-awareness

$$\sum_{\text{goal atoms } a} w_a = 0$$

Consistency

$$\sum_{\substack{a \text{ consumed} \\ \text{by } o}} w_a - \sum_{\substack{a \text{ produced} \\ \text{by } o}} w_a \leq \text{cost}(o) \quad \text{for all operators } o$$

Remarks:

- ▶ assumes transition normal form (not a limitation)
- ▶ goal-aware and consistent = admissible and consistent

Well-Informed Potential Heuristics

How to find a **well-informed** potential heuristic?

↪ encode **quality metric** in the **objective function**
and use LP solver to find a heuristic maximizing it

Examples:

- ▶ maximize **heuristic value of a given state** (e.g., initial state)
- ▶ maximize average heuristic value of **all states**
(including unreachable ones)
- ▶ maximize average heuristic value of some **sample states**
- ▶ minimize **estimated search effort**

D5.4 Connection to Flow Heuristic

Relationship to Flow Heuristic

Theorem

For state s , let $h^{\max\text{pot}}(s)$ denote the **maximal** heuristic value of all admissible and consistent atomic potential heuristics in s .

Then $h^{\max\text{pot}}(s) = h^{\text{flow}}(s)$.

Proof idea: compare dual of $h^{\text{flow}}(s)$ LP to potential heuristic constraints optimized for state s .

If we optimize the potentials for a given state then for this state it equals the flow heuristic.

D5.5 Summary

Summary

- ▶ General cost partitioning, operator-counting constraints and potential heuristics are **facets of the same phenomenon**
- ▶ Study of each reinforces understanding of the others.
- ▶ Potential heuristics can be used as **fast admissible approximations** of h^{low} .
- ▶ **Generalization beyond h^{low}** : use non-atomic features
- ▶ If features are cheap to compute, the **heuristic evaluation** for every state is extremely **fast**.

Literature

References on potential heuristics:

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