An Empirical Study of Perfect Potential Heuristics

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Motivation

Context:

- Optimal classical planning

Goals:

- Learn more about the topology of different domains
  - Study the characteristics of h^*
- Understand the limitations of potential heuristics

Potential Heuristics

- States are represented as sets of facts
- A feature f is a set of facts and it has size $|f|$
- A feature f is true in a state s if $f \subseteq s$

Definition (Potential Heuristic)

A weight function w associates a set of features $\mathcal{F}$ with weights. It induces a potential heuristic

$$h_w^{\text{pot}}(s) = \sum_{f \in \mathcal{F}} w(f)[f \subseteq s].$$

The dimension of h_w^{pot} is the size of its largest feature f.

- Higher dimension = more complex interactions between facts

Potential Heuristics

What if state s is unsolvable? Then $h^{\text{pot}}_{w}(s)$ should be ∞.

$$h_{w_1,w_2}(s) = \begin{cases} \infty & \text{if } h^{\text{pot}}_{w_2}(s) > 0 \\ h^{\text{pot}}_{w_1}(s) & \text{otherwise.} \end{cases}$$

h_{w_1,w_2} is a perfect potential heuristic if

- $h^{\text{pot}}_{w_1}(s)$ is perfect for all solvable states s
- $h^{\text{pot}}_{w_2}$ captures all unsolvable states correctly

Optimal Correlation Complexity

Definition (Optimal Correlation Complexity of a task)

The optimal correlation complexity of a planning task Π is the minimum dimension of a perfect potential heuristic for Π.

This gives us some insight about the complexity of the interactions between facts of the task.

Optimal Correlation Complexity

We study optimal correlation complexity of IPC domains empirically

Computing optimal correlation complexity is hard
We need...

- ...h^* for all (reachable) state space
- ...to find a good set of features
- ...to efficiently find a weight function

Computing a Perfect Potential Heuristic

Exact methods for finite and infinite values:

- Linear programs over the entire state space
- Initial set of candidate features $\mathcal{F}$; augment it as needed
- Potential heuristics found has optimal dimension

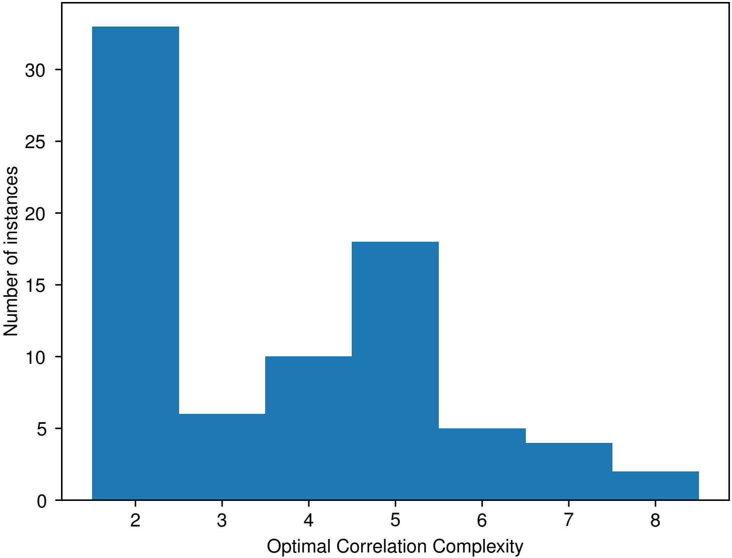
Experiments

Using Fast Downward and IPC domains

- 30 minutes and 3.5 GB per task
- 301 tasks over 38 domains where we can compute the perfect heuristic for the entire state space
  - Sample size is considerably small

Results

Histogram of optimal correlation complexities



Results

Lower bounds for the optimal correlation complexity per domain

Domain	Lower Bound
gripper	7
hiking-opt14	6
miconic	7
movie	2
nomystery-opt11	5
organic-synthesis-opt18	6
psr-small	8
rovers	8
scanalyzer-08	5
scanalyzer-opt11	5
storage	5
tpp	5
transport-opt08	6
vistall-opt11	8
zenotravel	4

Results

Lower bounds for the optimal correlation complexity per domain

Domain	Lower Bound
gripper	7→ 5
hiking-opt14	6
miconic	7→ 6
movie	2
nomystery-opt11	5→ 4
organic-synthesis-opt18	6→ 1
psr-small	8→ 4
rovers	8→ 5
scanalyzer-08	5
scanalyzer-opt11	5
storage	5→ 4
tpp	5→ 4
transport-opt08	6→ 4
visitall-opt11	8→ 7
zenotravel	4

Significant lower complexity considering only reachable states

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transport-opt08	6→ 4
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Significant lower complexity considering only reachable states
Also to detect unsolvable states

- Maximum dimension needed to detect unsolvable states was 3

Computing a (Quasi-)Perfect Potential Heuristic

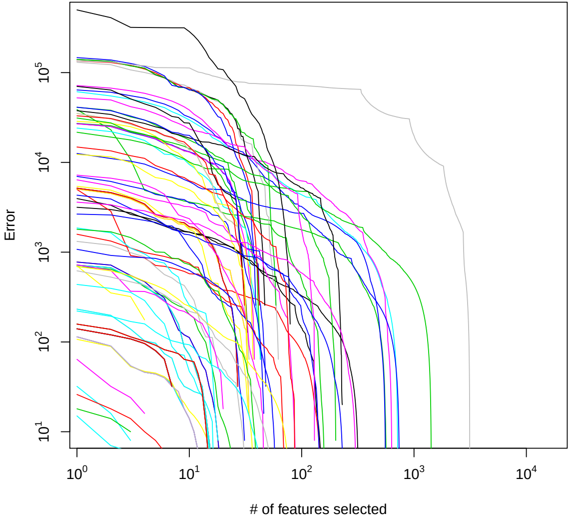
How close can we get with features of limited size?

Minimal Error for Finite Values:

- Starts with an "empty" potential heuristic
- Iteratively selects feature minimizing the error of the heuristic
- Once no feature up to size n reduces the error, add features of size $n + 1$ to feature pool

Results

Remaining error per feature added. (One line per instance.)



Results

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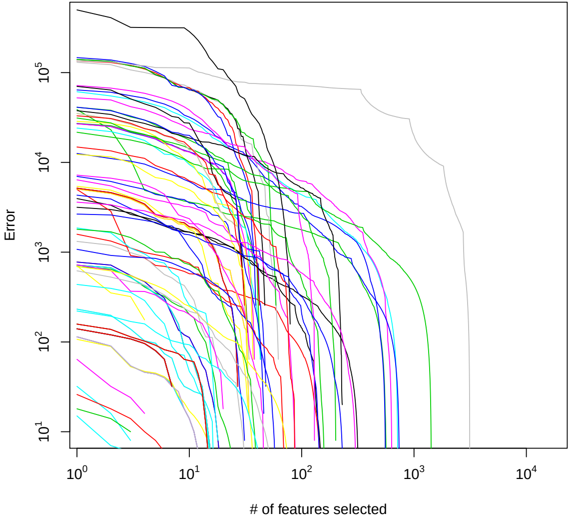

Only a few features of a given size are very important

Conclusion

Recap

- We investigated the "shape" of h^* in several domains
- Bad news: Even easy domains need perfect potential heuristics with high dimension
- Good news: Only a small number of large features already reduce the heuristic error significantly

Open Question

- How to automatically identify an informative subset of high-dimensional features?
  - We could find good weights using an FPT algorithm

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