Correlation Complexity of Classical Planning Domains

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Some Planning Tasks are Easy

- Domain independent planning is (PSPACE) hard.
- But some domains are easy.
- How can we quantify this?

A

B
## Related Concepts

### Width
- (macro-)persistent Hamming width  
  (Chen and Giménez, 2007; 2009)
- serialized iterated width  
  (Lipovetzky and Geffner, 2012; 2014)

### Search space topology
- Fixing the heuristic, how do search algorithms behave  
  (Hoffmann, 2005)

### Our approach
- Fixing the behavior of search algorithms, how complex does the heuristic need to be?
Main Question

How complex must a heuristic be to guide a forward search directly to the goal?
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• What does “guide directly to the goal” mean?
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How complex must a heuristic be to guide a forward search directly to the goal?

- What does “guide directly to the goal” mean?
- How can we measure the complexity of a heuristic?
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Heuristic Properties

- **alive state**: reachable + solvable + non-goal
- **descending**: all alive states have an improving successor
- **dead-end avoiding**: all improving successors of alive states are solvable
Main Question

How complex must a heuristic be to guide a forward search directly to the goal?

- What does “guide directly to the goal” mean? → descending and dead-end avoiding
- How can we measure the complexity of a heuristic?
Main Question

How complex must a heuristic be to guide a forward search directly to the goal?

- What does “guide directly to the goal” mean?
  → descending and dead-end avoiding

- How can we measure the complexity of a heuristic?
Potential Heuristics

States factored into facts
Features: conjunction of facts

Weights for features

\[ w \left( \frac{\bullet}{A} \right) = 8; \quad w \left( \begin{array}{c} \bullet \\ B \end{array} \right) = 1; \quad w (\bullet) = 4 \]

Heuristic value

\[ h \left( \begin{array}{c} \bullet \\ A \\ \bullet \\ B \end{array} \right) = 8 + 8 + 1 + 4 = 21 \]
Potential Heuristics

States factored into **facts**

**Features**: conjunction of facts

<table>
<thead>
<tr>
<th>Weights for features</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w\left(\begin{array}{c}A \ \end{array}\right) = 8$; $w\left(\begin{array}{c}B \ \end{array}\right) = 1$; $w\left(\begin{array}{c}B \ \end{array}\right) = 4$; $w\left(\begin{array}{c}B \ \end{array}\right) = -2$</td>
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<table>
<thead>
<tr>
<th>Heuristic value</th>
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<tr>
<td>$h\left(\begin{array}{c}A \ \end{array}\right) + 8 + 1 + 4 - 2 = 19$</td>
</tr>
</tbody>
</table>
Potential Heuristics

States factored into facts

Features: conjunction of facts

Weights for features

\[ w(A) = 8; \quad w(B) = 1; \quad w(\overline{A}) = 4; \quad w(\overline{B}) = -2 \]

Heuristic value

\[ h(A, B) = 8 + 8 + 1 + 4 - 2 = 19 \]

Dimension: number of facts in largest feature
Main Question

How complex must a heuristic be to guide a forward search directly to the goal?

- What does “guide directly to the goal” mean?
  - descending and dead-end avoiding

- How can we measure the complexity of a heuristic?
Main Question

How complex must a heuristic be to guide a forward search directly to the goal?

- What does “guide directly to the goal” mean?
  → descending and dead-end avoiding

- How can we measure the complexity of a heuristic?
  → dimension of potential heuristics
Correlation Complexity

Definition (correlation complexity of a planning task)
minimum dimension of a descending, dead-end avoiding potential heuristic for the task

Definition (correlation complexity of a planning domain)
maximal correlation complexity of all tasks in the domain
Correlation Complexity of Some Domains

**Correlation Complexity 2**
- Blocksworld without an arm
- Gripper
- Spanner
- VisitAll

**Correlation Complexity 3**
Construction based on 3-bit Gray code
Conclusion and Future Work

- New measure for the complexity of classical planning tasks.
- Measures how interrelated the task’s variables are.
- All studied benchmark domains have correlation complexity 2.
- Next: find good features and weights automatically.
Extra Slides
Gripper has Correlation Complexity 2

**Weight Function**

\[ w(r\text{-in}-B) = 1 \]
\[ w(b\text{-in}-A) = 8 \]
\[ w(b\text{-in}-G) = 4 \]
\[ w(r\text{-in}-B \land b\text{-in}-G) = -2 \]
Pick-up-in-A

\[ w(r\text{-in}\text{-}B) = 1, \quad w(b\text{-in}\text{-}A) = 8, \quad w(b\text{-in}\text{-}G) = 4, \quad w(r\text{-in}\text{-}B \land b\text{-in}\text{-}G) = -2 \]

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Move-to-B

\[ w(r\text{-in-}B) = 1, \ w(b\text{-in-}A) = 8, \ w(b\text{-in-}G) = 4, \ w(r\text{-in-}B \land b\text{-in-}G) = -2 \]

adds: \( r\text{-in-}B, \ r\text{-in-}B \land b\text{-in-}G \)
removes: 

difference: \( 1 + (-2) = -1 \)
Drop-in-B

\[ w(r\text{-}in\text{-}B) = 1, \quad w(b\text{-}in\text{-}A) = 8, \quad w(b\text{-}in\text{-}G) = 4, \quad w(r\text{-}in\text{-}B \land b\text{-}in\text{-}G) = -2 \]

adds: —
removes: b-in-G, r-in-B \land b-in-G
difference: \(-4 - (-2) = -2\)
Move-to-A

\[ w(r\text{-in-B}) = 1, w(b\text{-in-A}) = 8, w(b\text{-in-G}) = 4, w(r\text{-in-B} \land b\text{-in-G}) = -2 \]

- Adds: —
- Removes: \( r\text{-in-B} \)
- Difference: \(-1\)
Example Task with Correlation Complexity 3

- 3-bit Gray code: