Abstractions for Planning with State-Dependent Action Costs
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What are State-Dependent Action Costs?

Cost function:
\[
\text{cost}(\text{flyTo}(\text{London})) = |x_{\text{current}}| + |y_{\text{current}}|.
\]

Advantages:
- Structured and “natural”
- Exponentially more compact, fewer redundancies
- Relevant to applications

Edge-Valued Multi-Valued Decision Diagrams

Example: Decision diagram for function
\[\text{cost}_a = xy^2 + z + 2.\]

E.g., \(\text{cost}_a(1, 2, 0) = 2 + 0 + 4 + 0 = 6.\)

Advantages:
- Follow naturally from desired properties
- Exhibit additive structure
- Attribute partial costs to facts responsible for them
- Often compact

Properties:
- Existence
- Uniqueness (if reduced and ordered)
- Basic arithmetic operations supported

[\text{[Lai et al, 1996; Ciardo & Siminiceanu, 2002]}]

Abstraction Heuristics

Abstract Costs

Optimal planning with SDAC
\[\rightsquigarrow\text{admissible abstraction heuristics}\]

Minimize concrete costs!

Problem: exponentially many concrete states

Aim: Efficient computation

Cartesian Abstraction

Def.: A set of states \(s_{\text{abs}}\) is Cartesian if it is of the form \(D_1 \times \cdots \times D_n\), where \(D_i \subseteq D\), for all \(i = 1, \ldots, n\). An abstraction is Cartesian if all its abstract states are Cartesian sets.

[\text{Ball et al., 2001; Seipp & Helmert, 2013}]

Theorem: For Cartesian abstractions, a top-sort traversal of the cost EVMDD with local minimizations over those edges consistent with the abstract state correctly computes abstract costs.

Experiments

ACADEMIC ADVISING

TRIANGLE TIREWORLD

TAMARISK

SYSADMIN

Counterexample-Guided Abstraction Refinement

How to find Cartesian abstractions?

\[\rightsquigarrow\text{Counterexample-Guided Abstraction Refinement (CEGAR)}\]

Usual flaws, plus cost-mismatch flaw: action more costly in concrete state than in abstract state. Ex.:

\[
\begin{align*}
    a &= \langle T, x \land y \rangle, & \text{cost}_a &= 2x + 1 & s_0 &= 10 & s_x &= x \land y \\
    b &= \langle T, \neg x \land y \rangle, & \text{cost}_b &= 1
\end{align*}
\]

- Optimal abstract plan: \(a\) (abstract cost 1)
- This is also a concrete plan (concrete cost 3)
- Optimal concrete plan: \(b, a\) (conc. and abst. cost 2)

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