

Foundations of Artificial Intelligence

F6. Automated Planning: Abstraction Heuristics

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F6.1 Abstraction Heuristics

F6.2 Pattern Databases

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Automated Planning: Overview

Chapter overview: automated planning

- ▶ F1. Introduction
- ▶ F2. Planning Formalisms
- ▶ F3. Delete Relaxation
- ▶ F4. Delete Relaxation Heuristics
- ▶ F5. Abstraction
- ▶ F6. Abstraction Heuristics

F6.1 Abstraction Heuristics

Abstraction Heuristic

Given an abstraction function α for a state space \mathcal{S} , use **abstract solution cost** (solution cost of $\alpha(s)$ in \mathcal{S}^α) as heuristic for **concrete solution cost** (solution cost of s in \mathcal{S}).

Definition (abstraction heuristic)

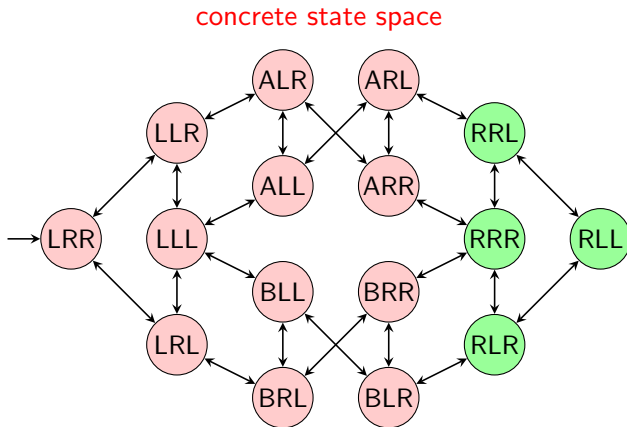
The **abstraction heuristic** for abstraction α maps each state s to its abstract solution cost

$$h^\alpha(s) = h_{\mathcal{S}^\alpha}^*(\alpha(s)),$$

where $h_{\mathcal{S}^\alpha}^*$ is the perfect heuristic in \mathcal{S}^α .

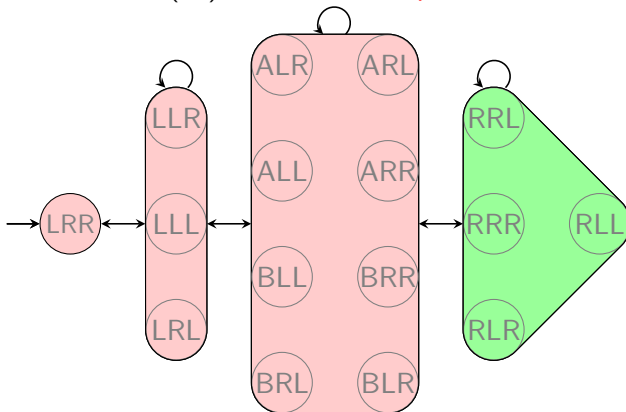
German: abstrakte/konkrete Zielabstände, Abstraktionsheuristik

Abstraction: Example



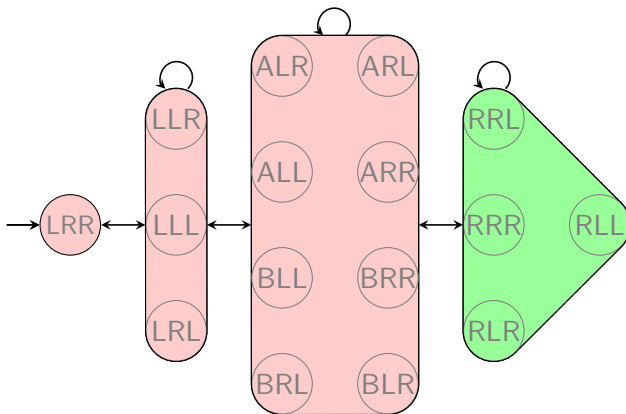
Abstraction: Example

(an) abstract state space



Remark: Most arcs correspond to several (parallel) transitions with different labels.

Abstraction Heuristic: Example



$$h^\alpha(\{p \mapsto L, t_A \mapsto R, t_B \mapsto R\}) = 3$$

Abstraction Heuristics: Discussion

- ▶ Every abstraction heuristic is **admissible** and **consistent**.
(proof idea?)
- ▶ The choice of the **abstraction function** α is very important.
 - ▶ **Every** α yields an admissible and consistent heuristic.
 - ▶ But most α lead to poor heuristics.
- ▶ An effective α must yield an **informative heuristic** ...
- ▶ ... as well as being **efficiently computable**.
- ▶ **How to find a suitable α ?**

Automatic Computation of Suitable Abstractions

Main Problem with Abstraction Heuristics

How to find a good abstraction?

Several successful methods:

- ▶ **pattern databases (PDBs)** \rightsquigarrow this course
(Culberson & Schaeffer, 1996)
- ▶ **merge-and-shrink** abstractions
(Dräger, Finkbeiner & Podelski, 2006)
- ▶ **Cartesian** abstractions (Seipp & Helmert, 2013)
- ▶ **domain** abstractions (Kreft et al., 2023)

German: Pattern Databases, Merge-and-Shrink-Abstraktionen, Kartesische Abstraktionen, Domänenabstraktionen

F6.2 Pattern Databases

Pattern Databases: Background

- ▶ The most common abstraction heuristics are **pattern database heuristics**.
- ▶ originally introduced for the **15-puzzle** (Culberson & Schaeffer, 1996) and for **Rubik's Cube** (Korf, 1997)
- ▶ introduced for **automated planning** by Edelkamp (2001)
- ▶ for many search problems the **best known** heuristics
- ▶ many many research papers studying
 - ▶ theoretical properties
 - ▶ efficient implementation and application
 - ▶ pattern selection
 - ▶ ...

Pattern Databases: Projections

A PDB heuristic for a planning task is an abstraction heuristic where

- ▶ some aspects (= state variables) of the task are preserved **with perfect precision** while
- ▶ all other aspects are not preserved **at all**.

formalized as **projections** to a **pattern** $P \subseteq V$:

$$\pi_P(s) = \{v \mapsto s(v) \mid v \in P\}$$

example:

- ▶ $s = \{p \mapsto L, t_A \mapsto R, t_B \mapsto R\}$
- ▶ **projection** on $P = \{p\}$ (= ignore trucks):
 $\pi_P(s) = \{p \mapsto L\}$
- ▶ **projection** on $P = \{p, t_A\}$ (= ignore truck B):
 $\pi_P(s) = \{p \mapsto L, t_A \mapsto R\}$

German: Projektionen

Pattern Databases: Definition

Definition (pattern database heuristic)

Let P be a subset of the variables of a planning task.

The abstraction heuristic induced by the projection π_P on P is called **pattern database heuristic (PDB heuristic)** with **pattern** P .

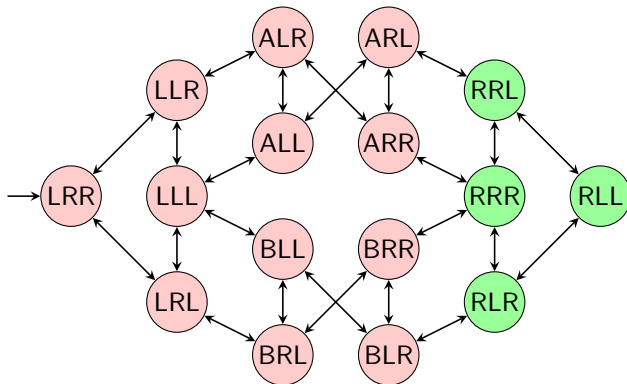
abbreviated notation: h^P for h^{π_P}

German: Pattern-Database-Heuristik

remark:

- ▶ “pattern databases” in analogy to **endgame databases** (which have been successfully applied in 2-person-games)

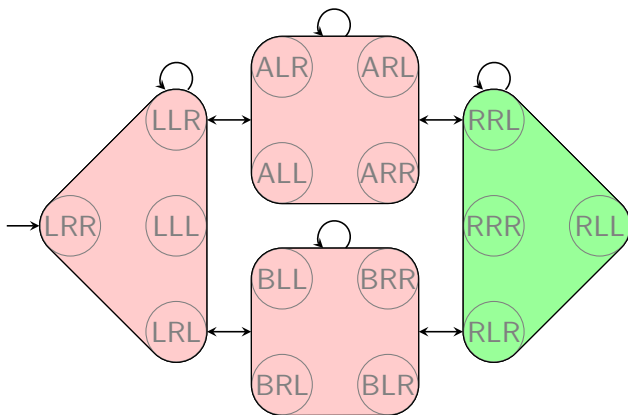
Example: Concrete State Space



- ▶ state variable *package*: {L, R, A, B}
- ▶ state variable *truck A*: {L, R}
- ▶ state variable *truck B*: {L, R}

Example: Projection (1)

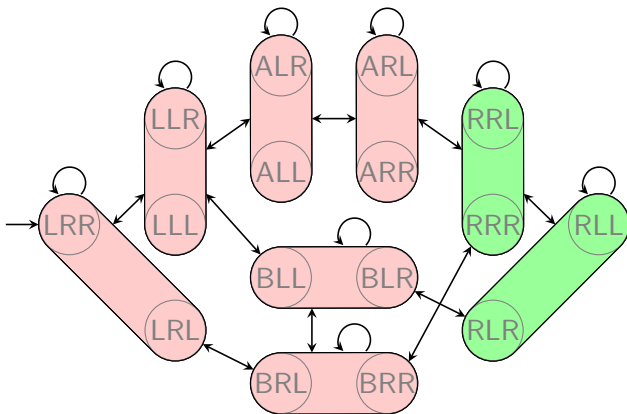
abstraction induced by $\pi_{\{package\}}$:



$$h^{\{package\}}(LRR) = 2$$

Example: Projection (2)

abstraction induced by $\pi_{\{package, truck A\}}$:



$$h_{\{package, truck A\}}(LRR) = 2$$

Pattern Databases in Practice

practical aspects which we do not discuss in detail:

- ▶ How to automatically find **good patterns**?
- ▶ How to combine **multiple** PDB heuristics?
- ▶ How to **implement** PDB heuristics efficiently?
 - ▶ good implementations efficiently handle **abstract** state spaces with 10^7 , 10^8 or more abstract states
 - ▶ effort independent of the size of the **concrete** state space
 - ▶ usually all heuristic values are precomputed
 - ↪ space complexity = number of abstract states

F6.3 Summary

Summary

- ▶ basic idea of **abstraction heuristics**: estimate solution cost by considering a **smaller** planning task.
- ▶ formally: **abstraction function** α maps states to **abstract states** and thus defines which states can be distinguished by the resulting heuristic.
- ▶ induces **abstract state space** whose solution costs are used as heuristic
- ▶ **Pattern database heuristics** are abstraction heuristics based on **projections** onto state variable subsets (**patterns**): states are distinguishable iff they differ on the pattern.