

Planning and Optimization

D2. Abstractions: Additive Abstractions

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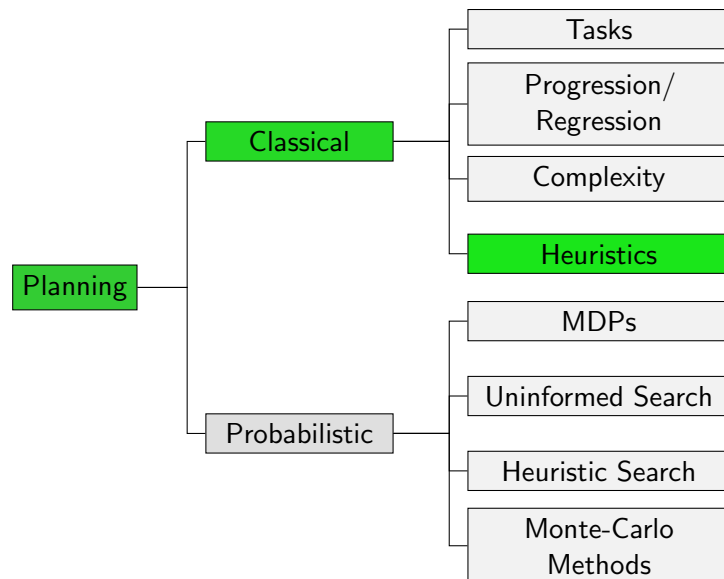
D2.1 Multiple Abstractions

D2.2 Additivity

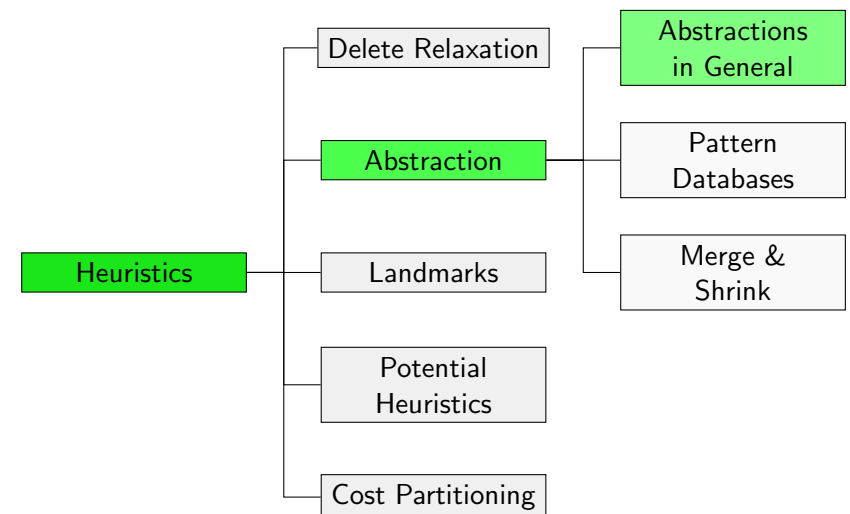
D2.3 Outlook

D2.4 Summary

Content of this Course



Content of this Course: Heuristics



D2.1 Multiple Abstractions

Multiple Abstractions

- ▶ One important practical question is how to come up with a suitable abstraction mapping α .
- ▶ Indeed, there is usually a **huge number of possibilities**, and it is important to pick good abstractions (i.e., ones that lead to informative heuristics).
- ▶ However, it is generally **not necessary to commit to a single abstraction**.

Combining Multiple Abstractions

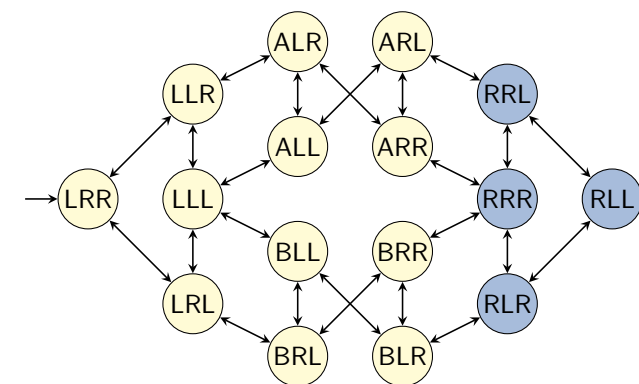
Maximizing several abstractions:

- ▶ Each abstraction mapping gives rise to an admissible heuristic.
- ▶ By computing the **maximum** of several admissible heuristics, we obtain another admissible heuristic which **dominates** the component heuristics.
- ▶ Thus, we can always compute several abstractions and maximize over the individual abstract goal distances.

Adding several abstractions:

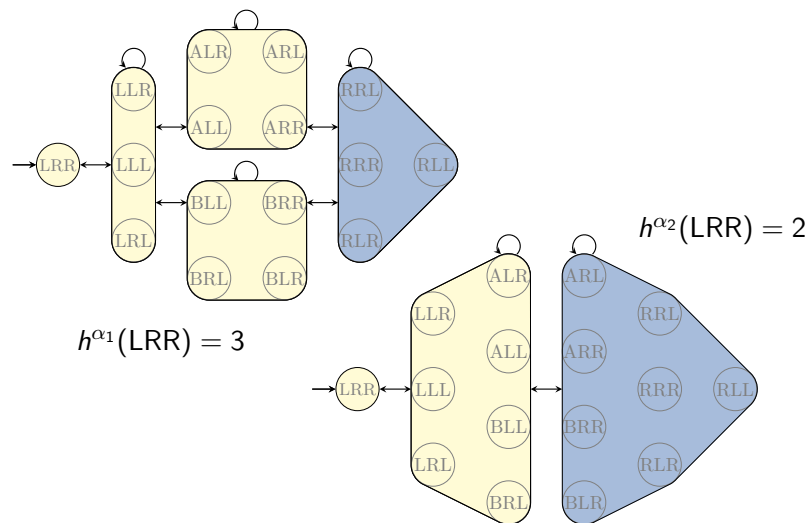
- ▶ In some cases, we can even compute the **sum** of individual estimates and still stay admissible.
- ▶ Summation often leads to **much higher estimates** than maximization, so it is important to understand **under which conditions** summation of heuristics is **admissible**.

Adding Several Abstractions: Example (1)

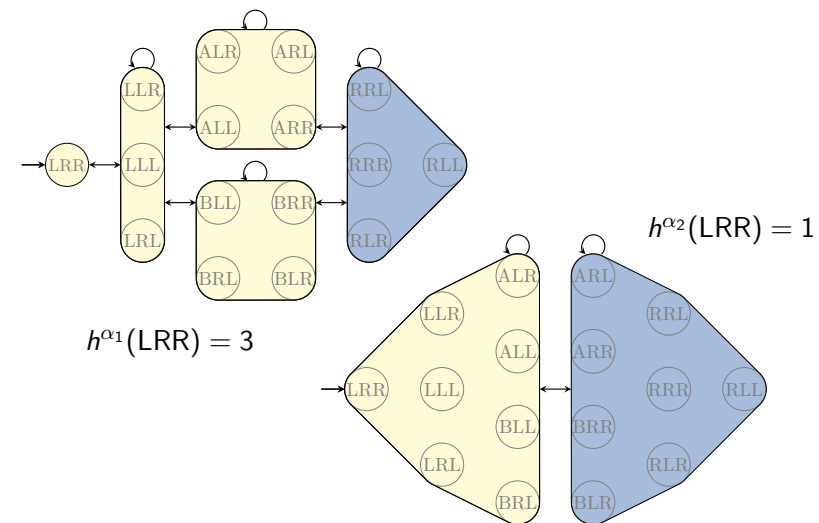


$$h^*(LRR) = 4$$

Adding Several Abstractions: Example (2)



Adding Several Abstractions: Example (3)



D2.2 Additivity

Orthogonality of Abstractions

Definition (Orthogonal)

Let α_1 and α_2 be abstractions of transition system \mathcal{T} .

We say that α_1 and α_2 are **orthogonal** if for all transitions $s \xrightarrow{\ell} t$ of \mathcal{T} , we have $\alpha_i(s) = \alpha_i(t)$ for at least one $i \in \{1, 2\}$.

Affecting Transition Labels

Definition (Affecting Transition Labels)

Let \mathcal{T} be a transition system, and let ℓ be one of its labels.

We say that ℓ **affects** \mathcal{T} if \mathcal{T} has a transition $s \xrightarrow{\ell} t$ with $s \neq t$.

Theorem (Affecting Labels vs. Orthogonality)

Let α_1 and α_2 be abstractions of transition system \mathcal{T} .

If no label of \mathcal{T} affects both \mathcal{T}^{α_1} and \mathcal{T}^{α_2} ,
then α_1 and α_2 are orthogonal.

(Easy proof omitted.)

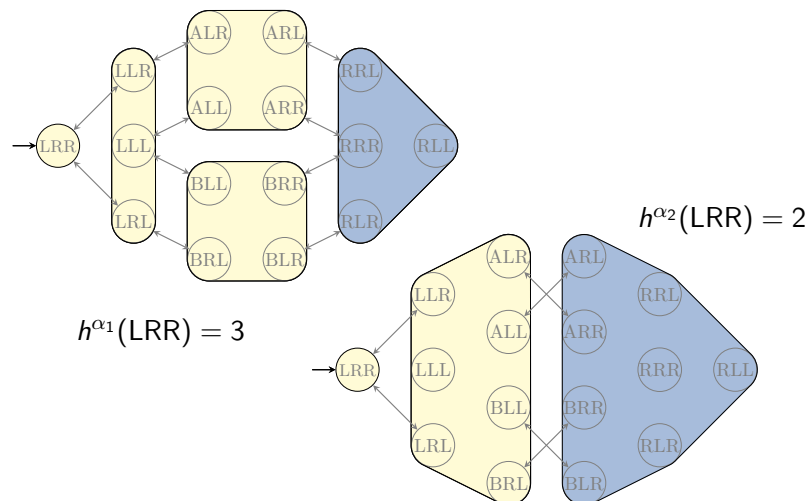
Orthogonality and Additivity

Theorem (Additivity for Orthogonal Abstractions)

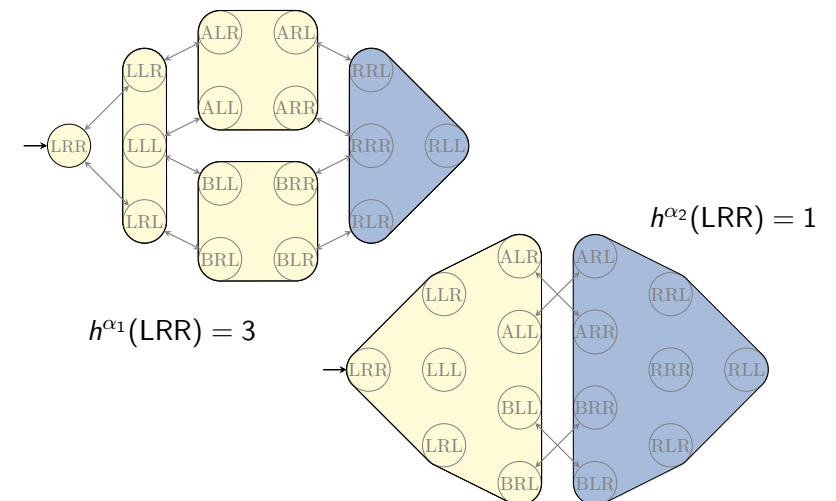
Let $h^{\alpha_1}, \dots, h^{\alpha_n}$ be abstraction heuristics of the same transition system such that α_i and α_j are orthogonal for all $i \neq j$.

Then $\sum_{i=1}^n h^{\alpha_i}$ is a safe, goal-aware, admissible and consistent heuristic for Π .

Orthogonality and Additivity: Example (1)



Orthogonality and Additivity: Example (2)



Orthogonality and Additivity: Proof (1)

Proof.

We prove goal-awareness and consistency; the other properties follow from these two.

Let $\mathcal{T} = \langle S, L, c, T, s_0, S_* \rangle$ be the concrete transition system.

Let $h = \sum_{i=1}^n h^{\alpha_i}$.

Goal-awareness: For goal states $s \in S_*$,

$h(s) = \sum_{i=1}^n h^{\alpha_i}(s) = \sum_{i=1}^n 0 = 0$ because all individual abstraction heuristics are goal-aware. ...

Orthogonality and Additivity: Proof (2)

Proof (continued).

Consistency: Let $s \xrightarrow{o} t \in T$. We must prove $h(s) \leq c(o) + h(t)$.

Because the abstractions are orthogonal, $\alpha_i(s) \neq \alpha_i(t)$ for **at most one** $i \in \{1, \dots, n\}$.

Case 1: $\alpha_i(s) = \alpha_i(t)$ for all $i \in \{1, \dots, n\}$.

$$\begin{aligned} \text{Then } h(s) &= \sum_{i=1}^n h^{\alpha_i}(s) \\ &= \sum_{i=1}^n h_{\mathcal{T}\alpha_i}^*(\alpha_i(s)) \\ &= \sum_{i=1}^n h_{\mathcal{T}\alpha_i}^*(\alpha_i(t)) \\ &= \sum_{i=1}^n h^{\alpha_i}(t) \\ &= h(t) \leq c(o) + h(t). \end{aligned} \dots$$

Orthogonality and Additivity: Proof (3)

Proof (continued).

Case 2: $\alpha_i(s) \neq \alpha_i(t)$ for exactly one $i \in \{1, \dots, n\}$.

Let $k \in \{1, \dots, n\}$ such that $\alpha_k(s) \neq \alpha_k(t)$.

$$\begin{aligned} \text{Then } h(s) &= \sum_{i=1}^n h^{\alpha_i}(s) \\ &= \sum_{i \in \{1, \dots, n\} \setminus \{k\}} h_{\mathcal{T}\alpha_i}^*(\alpha_i(s)) + h^{\alpha_k}(s) \\ &\leq \sum_{i \in \{1, \dots, n\} \setminus \{k\}} h_{\mathcal{T}\alpha_i}^*(\alpha_i(t)) + c(o) + h^{\alpha_k}(t) \\ &= c(o) + \sum_{i=1}^n h^{\alpha_i}(t) \\ &= c(o) + h(t), \end{aligned}$$

where the inequality holds because $\alpha_i(s) = \alpha_i(t)$ for all $i \neq k$ and h^{α_k} is consistent. \square

D2.3 Outlook

Using Abstraction Heuristics in Practice

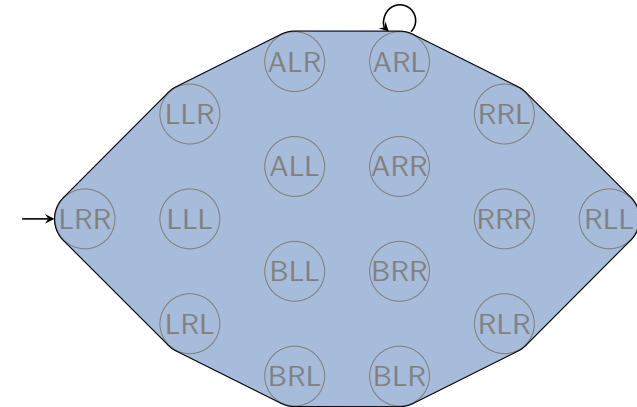
In practice, there are conflicting goals for abstractions:

- ▶ we want to obtain an **informative heuristic**, but
- ▶ want to keep its **representation small**.

Abstractions have small representations if

- ▶ there are **few abstract states** and
- ▶ there is a **succinct encoding for α** .

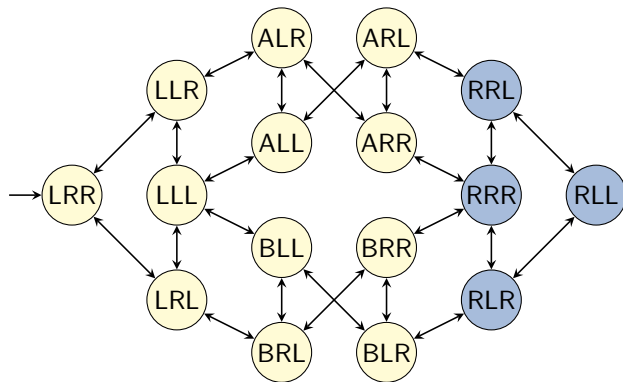
Counterexample: One-State Abstraction



One-state abstraction: $\alpha(s) := \text{const.}$

- + very few abstract states and succinct encoding for α
- completely uninformative heuristic

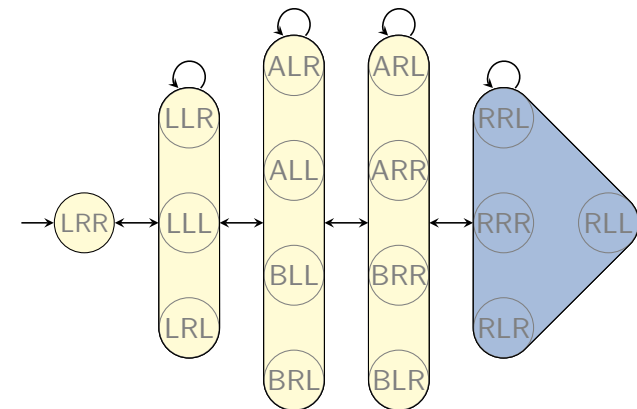
Counterexample: Identity Abstraction



Identity abstraction: $\alpha(s) := s$.

- + perfect heuristic and succinct encoding for α
- too many abstract states

Counterexample: Perfect Abstraction



Perfect abstraction: $\alpha(s) := h^*(s)$.

- + perfect heuristic and usually few abstract states
- usually no succinct encoding for α

Automatically Deriving Good Abstraction Heuristics

Abstraction Heuristics for Planning: Main Research Problem
Automatically derive effective abstraction heuristics
for planning tasks.

↪ we will study two state-of-the-art approaches
in Chapters D3–D8

D2.4 Summary

Summary

- ▶ Often, **multiple abstractions** are used.
They can always be **maximized** admissibly.
- ▶ **Adding** abstraction heuristics is not always admissible.
When it is, it leads to a stronger heuristic than maximizing.
- ▶ Abstraction heuristics from **orthogonal** abstractions
can be **added** without losing admissibility or consistency.
- ▶ One sufficient condition for orthogonality is that all
abstractions are **affected** by **disjoint** sets of **labels**.
- ▶ Practically useful abstractions are those which give
informative heuristics, yet have a **small representation**.
- ▶ Coming up with **good abstractions automatically**
is the main research challenge when applying
abstraction heuristics in planning.