Beyond Stars – Generalized Topologies for Decoupled Search

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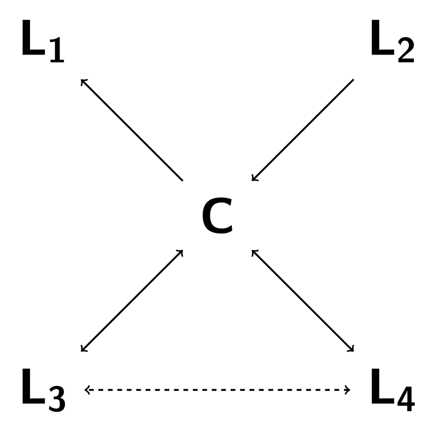
Context

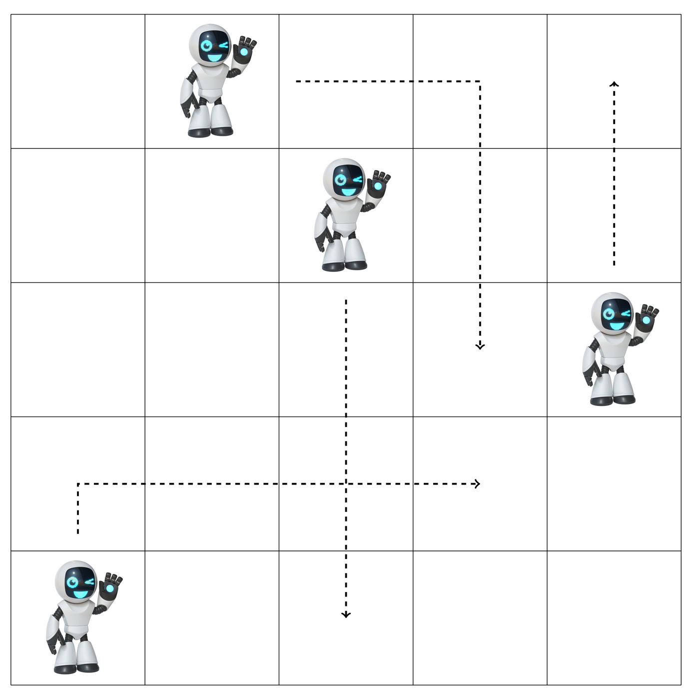
- Classical planning with finite-domain variables.
- Problem decomposition by partitioning state variables.
- Prior work: enforce "star topology":

Definition: Star Factoring

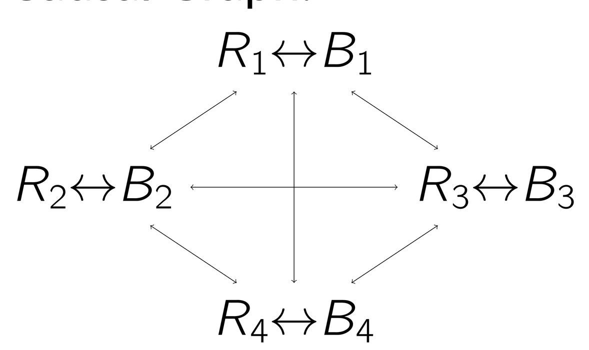
A pair $\mathcal{F}_s = \langle C, \mathcal{L}\rangle$ is a star factoring, if $\{C\} \cup \mathcal{L}$ is a factoring and for all actions $a \in \mathcal{A}$ either there exists an $L \in \mathcal{L}$ such that $vars(\mathsf{pre}(a)) \subseteq C \cup L$ and $vars(\mathsf{eff}(a)) \subseteq L$, or $vars(\mathsf{eff}(a)) \cap C \neq \emptyset$. C is called the **center factor** of $\mathcal{F}_s$, and $\mathcal{L}$ are its **leaf factors.**



Why generalize Topologies?



Causal Graph:



$move(R_i, B_i, l_x, l_y)$:
$\mathsf{pre}() = \{R_i = l_x, B_i = b\}$,
$\mathsf{eff}() = \{R_i = l_y, B_i = b - 1\}$
$charge(R_i, B_i, R_j, B_j)$:
$\mathsf{pre}() = \{R_i = R_j = l_x, B_i = b, B_j = c\}$,
$\mathsf{eff}() = \{B_i = b - 1, B_j = c + 1\}$

Generalized Factorings

Definition: Generalized Factoring

A pair $\mathcal{F}_g = \langle C, \mathcal{L}\rangle$ is a *generalized factoring*, if either $\mathcal{L}$ is a factoring or $\{C\} \cup \mathcal{L}$ is a factoring.

No additional structural requirements! How to handle interactions?

Definition: Global Action

Let $\mathcal{F}_g = \langle C, \mathcal{L}\rangle$ be a generalized factoring.
An action $a \in \mathcal{A}$ is a **global action** iff there does not exist an $L \in \mathcal{L}$ such that $vars(\mathsf{pre}(a)) \subseteq C \cup L$ and $vars(\mathsf{eff}(a)) \subseteq L$.

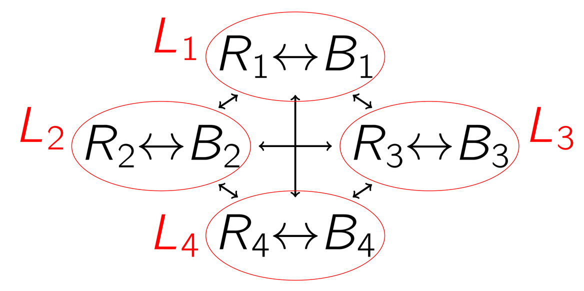
Avoid structural requirements of star factorings by generalizing to arbitrary topologies.

$\Downarrow$

Applicability in more domains.

Higher flexibility for factoring strategies.

Correspondence to Star Factorings



From generalized factoring $\mathcal{F}_g = \langle C_G, \mathcal{L}_G\rangle$ to star factoring $\mathcal{F}_s = \langle C_S, \mathcal{L}_S\rangle$:

- add new center variable x with $\mathcal{D}(x) = \{0\}$: $C_S = C_G \cup \{x\}$,
- for all global actions $a \in \mathcal{A}$, add effect $\{x = 0\}$,
- nothing changes for leaf-only actions.

Inherit all properties of star-decoupled search: soundness, completeness, optimality preservation.

Finding Generalized Factorings

- Factoring process as **integer linear program** (ILP).
- Any **partition of the state variables** is a factoring.
- **Optimize important properties** of the factoring:
  - Number of leaves,
  - Balanced mobility: # leaf-only actions (product),
  - Mobility: number of leaf-only actions (sum),
  - Flexibility: ratio of leaf-only actions (facts).
- **Require minimum flexibility** $\{0\%, 5\%, \ldots 100\%\}$.
- Leaf candidates: **action effect schemas** $vars(\mathsf{eff}(a))$ and **SCCs of causal graph.**

Coverage over minimum Flexibility