Towards Automated Modeling Assistance: An Efficient Approach for Repairing Flawed Planning Domains

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Motivation and Objective

The task of modeling a planning domain is a major obstacle for deploying AI planning techniques more broadly.

- We need tools for modeling assistance!
  - E.g., Planning.Domains, itSIMPLE, plugin(s) for Visual Studio Code, etc.
- We want to repair a flawed planning domain.

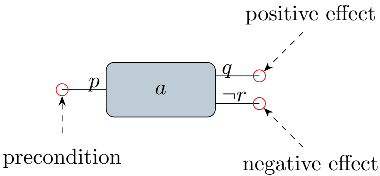
Objective

- **Inputs**: A flawed planning domain.
  A (set of) plan(s) contradicting the flawed domain but demanded to be valid.
- **Output**: A *cardinality-minimal* repair set to the domain that turns each plan into a solution.

Background

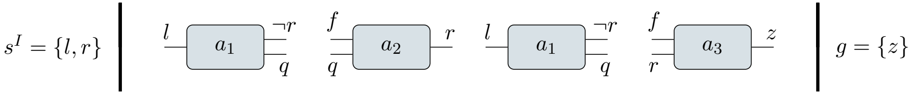
A planning problem is $\Pi = (\mathcal{D}, s^I, g)$ where $\mathcal{D} = (\mathcal{F}, \mathcal{A}, \alpha)$ is the domain of Π.

- $\mathcal{F}$: A finite set of propositions.
- $\mathcal{A}$: A finite set of action names.
- $\alpha : \mathcal{A} \to 2^{\mathcal{F}} \times 2^{\mathcal{F}} \times 2^{\mathcal{F}}$ mapping each action name to its precondition and effects.



- $s^I \in 2^{\mathcal{F}}$: The initial state.
- $g \subseteq \mathcal{F}$: The goal description.

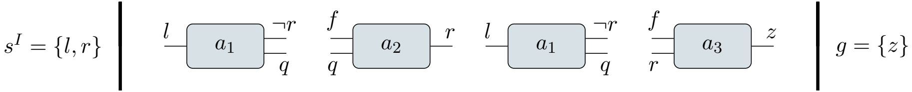
Atomic Repairs



For each action $a \in \mathcal{A}$, we define the atomic repairs:

- $\langle F_a|^p_f \rangle$: Removing the proposition f from a's precondition.
    - E.g., $\langle F_{a_3}|^p_r \rangle$ removes r from a_3's precondition.
- $\langle F_a|^-_f \rangle$: Removing the proposition f from a's negative effects.
    - E.g., $\langle F_{a_1}|^-_r \rangle$ removes r from a_1's negative effects.
- $\langle F_a|^+_f \rangle$: Adding the proposition f to a's positive effects.
    - E.g., $\langle F_{a_2}|^+_f \rangle$ adds f to a_2's positive effects.

Approach



Solution

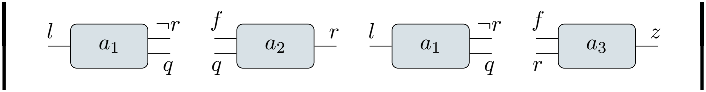
A cardinality-minimal set $\delta^* \subseteq F_\Pi$ with F_Π being the set of all atomic repairs that turns the plan into a solution.

We maintain a set of sets (of repairs) Θ^* which is initially empty.

- On each iteration, we find a set θ of repairs in which at least one *must* be applied for making the plan valid. Then, we add θ into Θ^*.
  - Such a θ is called a *conflict*.
- A *hitting set* δ of Θ^* is a set such that $\delta \cap \theta \neq \emptyset$ holds for every $\theta \in \Theta^*$. δ^* denotes a *minimal* hitting set of Θ^* (minimal number of repairs).

Computing a Conflict

$s^I = \{l, r\}$

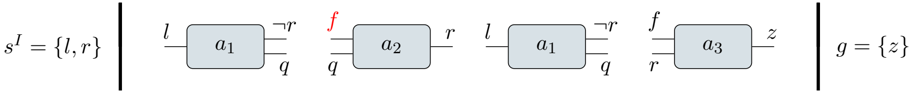


$g = \{z\}$

Given a plan $\langle a_1 \cdots a_n \rangle$, let a_j be the first action in the plan having a precondition f that is unsatisfied.

- $\langle F_{a_j}|^p_f \rangle$ is in the conflict.
- For each $i < j$ in descending order:
  - If a_i deletes f, $\langle F_{a_i}|^-_f \rangle$ is in the conflict, and we can stop the computation.
  - Otherwise, $\langle F_{a_i}|^+_f \rangle$ is in the conflict.
- E.g., $\left\{ \langle F_{a_2}|^p_f \rangle, \langle F_{a_1}|^+_f \rangle \right\}$ is a conflict.

Example



Iteration #1

- $\Theta^* = \emptyset$
- $\delta_1 = \emptyset$
- $\theta_1 = \left\{ \begin{matrix} \langle F_{a_2}|^{p}_{f}\rangle \\ \langle F_{a_1}|^{+}_{f}\rangle \end{matrix} \right\}$
- $\Theta^* = \{\theta_1\}$

Iteration #2

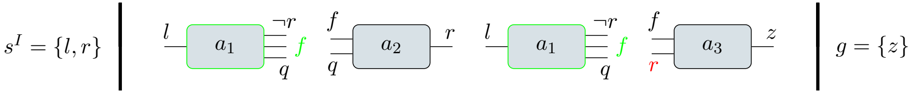
- $\Theta^* = \{\theta_1\}$
- $\delta_2 = \langle F_{a_1}|^{+}_{f}\rangle$
- $\theta_2 = \left\{ \begin{matrix} \langle F_{a_3}|^{p}_{r}\rangle \\ \langle F_{a_1}|^{-}_{r}\rangle \end{matrix} \right\}$
- $\Theta^* = \{\theta_1, \theta_2\}$

Iteration #3

- $\Theta^* = \{\theta_1, \theta_2\}$
- $\delta_3 = \left\{ \begin{matrix} \langle F_{a_1}|^{+}_{f}\rangle \\ \langle F_{a_1}|^{-}_{r}\rangle \end{matrix} \right\}$
- $\Theta^* = \{\theta_1, \theta_2\}$
- Done!

- Each δ_i is a minimal hitting set of Θ^*.
  - $\delta_3 = \delta^*$ is a solution.
- Each θ_i is a conflict.

Example



Iteration #1

- $\Theta^* = \emptyset$
- $\delta_1 = \emptyset$
- $\theta_1 = \begin{Bmatrix} \langle F_{a_2}|_f^p\rangle \\ \langle F_{a_1}|_f^+\rangle \end{Bmatrix}$
- $\Theta^* = \{\theta_1\}$

Iteration #2

- $\Theta^* = \{\theta_1\}$
- $\delta_2 = \langle F_{a_1}|_f^+\rangle$
- $\theta_2 = \begin{Bmatrix} \langle F_{a_3}|_r^p\rangle \\ \langle F_{a_1}|_r^-\rangle \end{Bmatrix}$
- $\Theta^* = \{\theta_1, \theta_2\}$

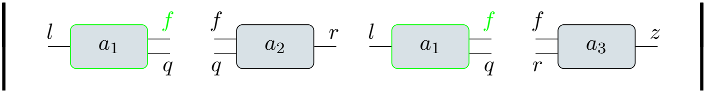
Iteration #3

- $\Theta^* = \{\theta_1, \theta_2\}$
- $\delta_3 = \begin{Bmatrix} \langle F_{a_1}|_f^+\rangle \\ \langle F_{a_1}|_r^-\rangle \end{Bmatrix}$
- $\Theta^* = \{\theta_1, \theta_2\}$
- Done!

- Each δ_i is a minimal hitting set of Θ^*.
  - $\delta_3 = \delta^*$ is a solution.
- Each θ_i is a conflict.

Example

$s^I = \{l, r\}$



$g = \{z\}$

Iteration #1

- $\Theta^* = \emptyset$
- $\delta_1 = \emptyset$
- $\theta_1 = \left\{ \begin{array}{l} \langle F_{a_2}|^p_f \rangle \\ \langle F_{a_1}|^+_f \rangle \end{array} \right\}$
- $\Theta^* = \{\theta_1\}$

Iteration #2

- $\Theta^* = \{\theta_1\}$
- $\delta_2 = \langle F_{a_1}|^+_f \rangle$
- $\theta_2 = \left\{ \begin{array}{l} \langle F_{a_3}|^p_r \rangle \\ \langle F_{a_1}|^-_r \rangle \end{array} \right\}$
- $\Theta^* = \{\theta_1, \theta_2\}$

Iteration #3

- $\Theta^* = \{\theta_1, \theta_2\}$
- $\delta_3 = \left\{ \begin{array}{l} \langle F_{a_1}|^+_f \rangle \\ \langle F_{a_1}|^-_r \rangle \end{array} \right\}$
- $\Theta^* = \{\theta_1, \theta_2\}$
- Done!

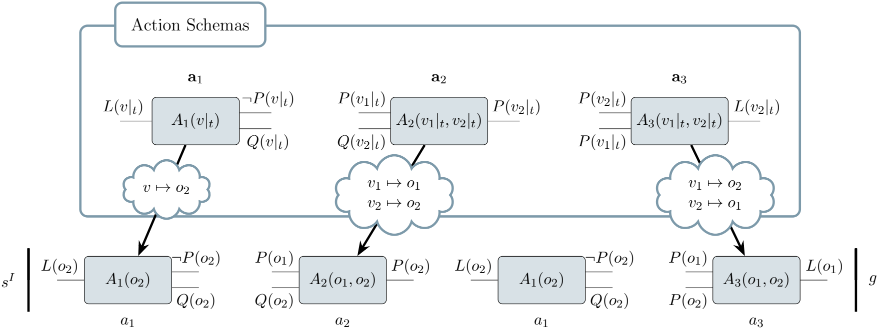
- Each δ_i is a minimal hitting set of Θ^*.
  - $\delta_3 = \delta^*$ is a solution.
- Each θ_i is a conflict.

Lifted Planning Formalism

A *lifted* problem is $\mathbf{\Pi} = (\mathcal{D}, \mathcal{O}, s^I, g)$ with $\mathcal{D} = (\mathcal{P}, \mathcal{A}, \alpha)$:

- $\mathcal{O}$: A set of *objects*.
  - Each object has a *type*.
- $\mathcal{P}$: A set of *predicates*.
  - E.g., $\mathbf{f} = P(v_1|_{t_1}, \cdots, v_n|_{t_n})$ where P is the predicate's name, $v_i \in \mathcal{V}$ is a variable, and t_i is the respective type.
- $\mathcal{A}$: A set of *action schemas*.
  - E.g., $\mathbf{a} = A(v_1|_{t_1}, \cdots, v_n|_{t_n})$ where A is the action's name.
  - α maps each action schema to its precondition and effects, each of which is a set of predicates $\mathbf{f}$.
    - E.g., $\mathbf{f} = P(v_{i_1}|_{t_{i_1}}, \cdots, v_{i_j}|_{t_{i_j}})$ with $i_k \in \{1, \cdots, n\}$ for each $k \in \{1, \cdots, j\}$.
- Substituting each variable with an object of the same type is called grounding.

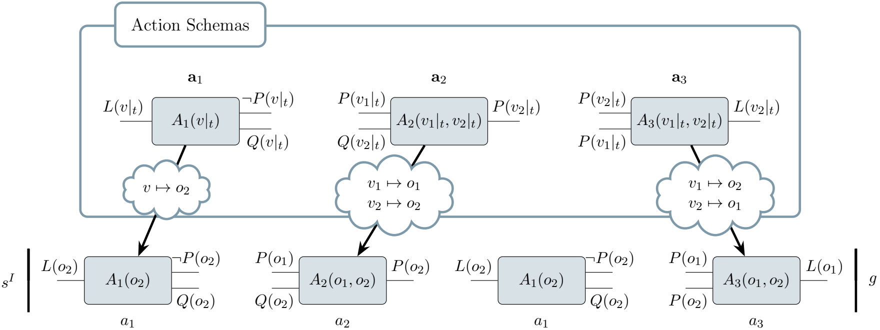
Lifted Domain Repair Problem



For an action schema $\mathbf{a}$, an atomic repair is one of the following:

- $\langle \mathbf{F_a}|_\mathbf{f}^p \rangle$: Removing the predicate $\mathbf{f}$ from $\mathbf{a}$'s precondition.
- $\langle \mathbf{F_a}|_\mathbf{f}^- \rangle$: Removing $\mathbf{f}$ from $\mathbf{a}$'s negative effects.
- $\langle \mathbf{F_a}|_\mathbf{f}^+ \rangle$: Adding $\mathbf{f}$ to $\mathbf{a}$'s positive effects.
    - The parameters of $\mathbf{f}$ must align with those of $\mathbf{a}$.
    - E.g., $\langle \mathbf{F_{a_2}}|_\mathbf{f}^+ \rangle$ with $\mathbf{f} = Q(v_1|_t)$ or $\mathbf{f} = Q(v_2|_t)$

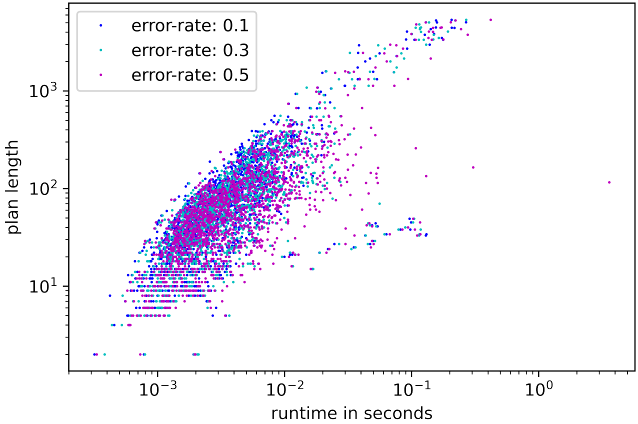
Solving the Lifted Domain Repair Problem



Let a_j be the first action in the plan having a proposition f in its precondition that is unsatisfied, e.g., $f = P(o_1)$ in a_2.

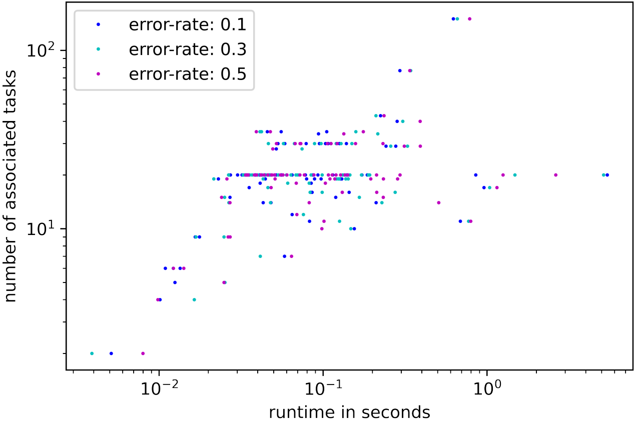
- $\langle \mathbf{F_a}|^p_\mathbf{f} \rangle$ is in the conflict if $\mathbf{a}$ and $\mathbf{f}$ are grounded to a_j and f, respectively. E.g., $\langle \mathbf{F}_{\mathbf{a}_2}|^p_\mathbf{f} \rangle$ with $\mathbf{f} = P(v_1|_t)$.
- $\langle \mathbf{F_a}|^+_\mathbf{f} \rangle$ is in the conflict if $\mathbf{a}$ and $\mathbf{f}$ are grounded to an a_i $(i < j)$ and f, respectively. (Such $\mathbf{a}$ and $\mathbf{f}$ does *not* exist for $\mathbf{a}_1$.)
- Stop at a_i, $i < j$, if there exists $\langle \mathbf{F_a}|^-_f \rangle$ with $\mathbf{a}$ and $\mathbf{f}$ being grounded to a_i and f.

Empirical Evaluation (with Single Plan)



The plot depicts the runtime for repairing domains where one plan is given. (Up to > 1000 plan length.)

Empirical Evaluation (with Multiple Plans)



This plot depicts the runtime for repairing domain where multiple plans are given. (Up to > 100 plans.)

Conclusion

We developed an approach for repairing planning domains:

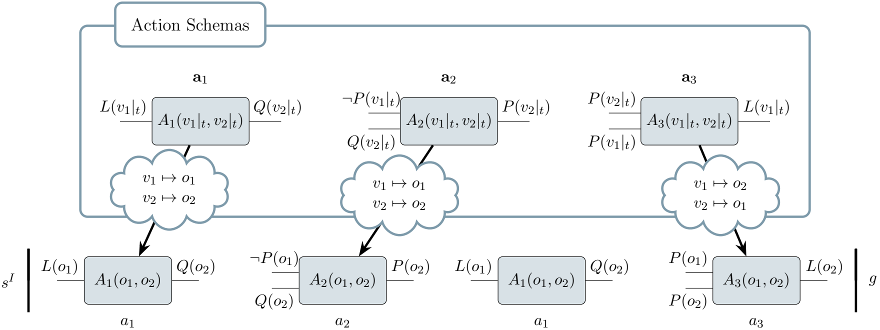
- The approach works for both grounded and lifted planning domains (both shown),
- both with and without negative preconditions (the latter wasn't shown).
- We support repairing a single plan and *sets* of plans.
- **Approach can be used to repair unsolvable problems!**
- Most domains in our benchmark set can be repaired within *one* second.

Future Work

Possible and planned directions of future work are:

- Building an interactive tool for repairing domains. (Plugin for Planning.Domains)
- Extending the approach to support more advanced features, e.g.,
  - negative plans (which plans should be rejected?)
  - change parameters (see first action in lifted example: should we allow to add the effect?)
  - block certain repairs (should we allow adding an effect if it already gets deleted?)
  - and possibly many more!

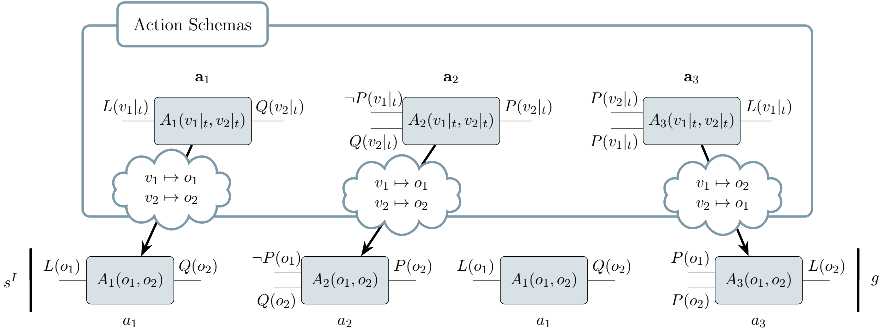
Lifted Domain Repair Problems with Negative Preconditions



For each $\mathbf{a}$, we define the following *additional* atomic repairs:

- $\langle \mathbf{N_a}|^p_{\mathbf{f}} \rangle$: Removing $\mathbf{f}$ from $\mathbf{a}$'s *negative* precondition.
- $\langle \mathbf{N_a}|^-_{\mathbf{f}} \rangle$: *Adding* $\mathbf{f}$ to $\mathbf{a}$'s negative effects.
  - The parameters of $\mathbf{f}$ must align with those of $\mathbf{a}$.
- $\langle \mathbf{N_a}|^+_{\mathbf{f}} \rangle$: *Removing* $\mathbf{f}$ from $\mathbf{a}$'s positive effects.

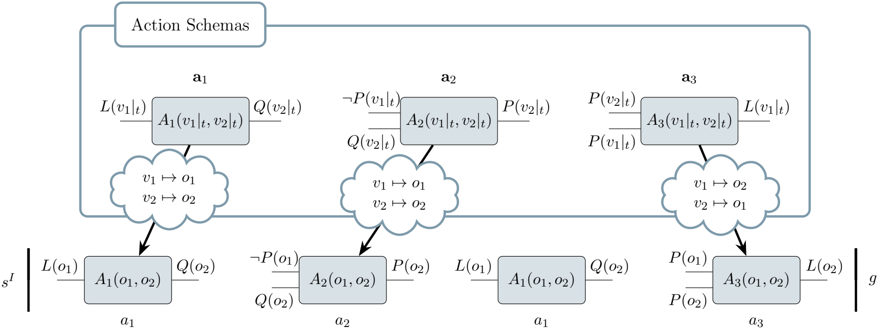
Conditional Conflicts



A repair set is now *not* a hitting set of a conflict set.

- A repair may result in violating some action's precondition.
  - E.g., $\langle \mathbf{F}_{\mathbf{a}_1}|^+_{\mathbf{f}} \rangle$ with $\mathbf{f} = P(v_1|_t)$ will make a_3 applicable and make a_2 *inapplicable*.
- We need to compute *conditional* conflicts (φ, θ).
  - If all repairs in φ are applied to the domain, then at least one repair in θ must be applied.

Computing Conditional Conflicts



We first compute a conflict θ using the same way as before.

- If θ has some repair that undoes a previous applied repair, then we remove it from θ and add it to the condition φ.
- E.g., assuming that $P(v_1|_t)$ is added to $\mathbf{a}_1$'s positive effect.
  - $\theta = \{\langle \mathbf{N}_{\mathbf{a}_2}|^p_{\mathbf{f}}\rangle, \langle \mathbf{N}_{\mathbf{a}_1}|^-_{\mathbf{f}}\rangle\}$ with $\mathbf{f} = P(v_1|_t)$.
  - Removing $\langle \mathbf{N}_{\mathbf{a}_1}|^-_{\mathbf{f}}\rangle$ from θ and adding $\langle \mathbf{F}_{\mathbf{a}_1}|^+_{\mathbf{f}}\rangle$ to φ.
    - $\langle \mathbf{N}_{\mathbf{a}_1}|^-_{\mathbf{f}}\rangle$ undoes $\langle \mathbf{F}_{\mathbf{a}_1}|^+_{\mathbf{f}}\rangle$.