Expressing and Exploiting the Common Subgoal Structure of Classical Planning Domains Using Sketches

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Classical planning (deterministic + fully observable)
We consider tractable domains with domain general strategy
How vs what to achieve? (Policy vs Subgoal)
Our contribution:
- Encode subgoal structure using language of policy sketches [Bonet and Geffner, 2021]
- Domains provably solvable in low poly time
- Search methods: iterated width, serialization [Lipovetzky and Geffner, 2012]
Width $w(P)$ measures difficulty to solve a planning problem $P$

- **Width** depends on goal that we want to achieve

- **Theorem:** if $w(P) \leq k$ then $\text{IW}(k)$ solves $P$ optimally in $\exp(k)$ time

- $\text{IW}(k)$ is breadth-first search where state $s$ is pruned if $\text{novelty}(s) > k$
The Problem of Unbounded Width

- **Single goal atom** ⇒ often small width
- **Conjunctive goals** ⇒ often unbounded width
  - **Serialized Iterated Width (SIW)**
    - SIW(k) runs sequence of IW(k) searches
    - Each IW(k) search **decreases goal count heuristic** \( \#g \)
    - Subproblems: achieve single goal atom
- SIW still fails if ...
  - it traps into an unsolvable state
  - it generates a subproblem of greater width
  - the subproblem has too large width
- **Policy sketches is a language for defining richer problem decompositions**
Example Domain: Floortile Dynamics

Figure: Plan execution
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Example Domain: Floortile SIW Failure

(a) Initial state $s_0: \#g = 4$

- **Features** $\Phi = \{\#g\}$
- **Sketch** $R_\Phi = \{r\}$ with $r = \{\#g > 0\} \mapsto \{\#g\downarrow\}$
- Serialization according to $R_\Phi$: $\text{SIW}_{R_\Phi} = \text{SIW}$
- SIW traps into unsolvable state
Example Domain: Floortile SIW Failure

(a) Unsolvable state $s_1$: $\#g = 3$

- **Features** $\Phi = \{\#g\}$
- **Sketch** $R_\Phi = \{r\}$ with $r = \{\#g > 0\} \mapsto \{\#g \downarrow\}$
- Serialization according to $R_\Phi$: $SIW_{R_\Phi} = SIW$
- SIW traps into unsolvable state
Example Domain: Floortile Sketch

(a) Initial state $s_0$: $\#g = 4$, $\text{Solvable} = T$

- **Features** $\Phi = \{ \#g, \text{Solvable} \}$
- **Sketch** $R_\Phi = \{ r \}$ with $r = \{ \#g > 0, \text{Solvable} \} \mapsto \{ \#g \downarrow \}$
- **Theorem**: $R_\Phi$ terminates and $w_{R_\Phi}(Q) = 2$
Example Domain: Floortile Sketch

(a) Rule $r$ leads to $s_3$: $\#g = 3$, $\text{Solvable} = \top$

- **Features** $\Phi = \{\#g, \text{Solvable}\}$
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Example Domain: Floortile Sketch

(a) Rule $r$ leads to $s_6$: \#$g = 2$, Solvable = $\top$

- **Features** $\Phi = \{\#g, \text{Solvable}\}$
- **Sketch** $R_\Phi = \{r\}$ with $r = \{\#g > 0, \text{Solvable}\} \rightarrow \{\#g \downarrow\}$
- **Theorem:** $R_\Phi$ terminates and $w_{R_\Phi}(Q) = 2$
Example Domain: Floortile Sketch

(a) Rule $r$ leads to $s_9$: $\#g = 1$, $\text{Solvable} = \top$

- Features $\Phi = \{\#g, \text{Solvable}\}$
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Example Domain: Floortile Sketch

(a) Rule $r$ leads to goal $s_{12}$: $\#g = 0$, \textit{Solvable} = $\top$

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**Figure:** Plan execution
Example Domain: Barman

![Initial state diagram](image)

- **SIW** fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \text{dirtyShots}, \text{Consistent}_1, \text{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$
  - $r_1 = \{\neg \text{Consistent}_1\} \leftrightarrow \{\text{dirtyShots}\?, \text{Consistent}_1\}$,
  - $r_2 = \{\text{Consistent}_1, \neg \text{Consistent}_2\} \leftrightarrow \{\text{dirtyShots}\?, \text{Consistent}_2\}$,
  - $r_3 = \{\text{dirtyShots} > 0\} \leftrightarrow \{\text{dirtyShots}\downarrow\}$,
  - $r_4 = \{\#g > 0\} \leftrightarrow \{\#g\downarrow, \text{Consistent}_1\?, \text{Consistent}_2\?\}$.
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**Figure:** Rule $r_3$ leads to $s3$
### Example Domain: Barman

#### Figure: Rule $r_2$ leads to $s_5$

- **SIW** fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \text{dirtyShots}, \text{Consistent}_1, \text{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$
  - $r_1 = \{\neg \text{Consistent}_1\} \mapsto \{\text{dirtyShots}?, \text{Consistent}_1\}$,
  - $r_2 = \{\text{Consistent}_1, \neg \text{Consistent}_2\} \mapsto \{\text{dirtyShots}?, \text{Consistent}_2\}$,
  - $r_3 = \{\text{dirtyShots} > 0\} \mapsto \{\text{dirtyShots}\downarrow\}$,
  - $r_4 = \{\#g > 0\} \mapsto \{\#g\downarrow, \text{Consistent}_1?, \text{Consistent}_2?\}$.
- **Theorem**: $R_\Phi$ terminates and $w_{R_\Phi}(Q) = 2$
Example Domain: Barman

![Image of a shot and shaker](image)

<table>
<thead>
<tr>
<th>Part 1</th>
<th>Part 2</th>
<th>Cocktail</th>
</tr>
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<tbody>
<tr>
<td><img src="image" alt="Green drink" /></td>
<td><img src="image" alt="Blue drink" /></td>
<td><img src="image" alt="Cocktail" /></td>
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<tr>
<td><img src="image" alt="Red drink" /></td>
<td><img src="image" alt="Blue drink" /></td>
<td><img src="image" alt="Goal" /></td>
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</table>

**Figure:** Rule $r_3$ leads to $s_6$

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \text{dirtyShots}, \text{Consistent}_1, \text{Consistent}_2\}$
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  $r_3 = \{dirtyShots > 0\} \rightarrow \{dirtyShots\downarrow\}$,
  
  $r_4 = \{\#g > 0\} \rightarrow \{\#g\downarrow, Consistent_1?, Consistent_2?\}$.

- **Theorem:** $R_\Phi$ terminates and $w_{R_\Phi}(Q) = 2$
## Experiments

<table>
<thead>
<tr>
<th>Domain</th>
<th>SIW(2)</th>
<th>SIW&lt;sub&gt;R&lt;/sub&gt;(2)</th>
<th>LAMA</th>
<th>Dual-BFWS</th>
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<tr>
<td></td>
<td>S</td>
<td>T</td>
<td>AW</td>
<td>MW</td>
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<tr>
<td>Barman (40)</td>
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<td>–</td>
<td>–</td>
<td>–</td>
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<td>Childsnack (20)</td>
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<td>74.7</td>
<td>2.00</td>
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</tr>
</tbody>
</table>

| # Domains solved | 0/7   | 7/7    | 5/7   | 4/7   |
Conclusions and Future Work

Conclusions:
- We presented compact encoding of subgoals
- Provide deeper domain understanding and poly runtime guarantees

Future work:
- Learn sketches automatically, unsupervised from small instances
- Learn hierarchies