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

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In a Nutshell

- **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 & Iterated Width (IW) [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 IW(k) **solves** P optimally in exp(k) time
- IW(k) is breadth-first search where state s is pruned if $novelty(s) > k$

The Problem of Unbounded Width

- **Single goal atom** $\Rightarrow$ often small width
- **Conjunctive goals** $\Rightarrow$ 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

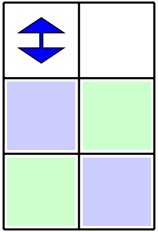
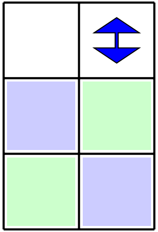


Figure: Plan execution

Example Domain: Floortile Dynamics



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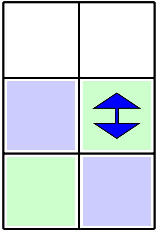

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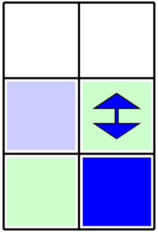

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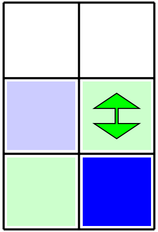

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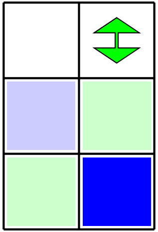

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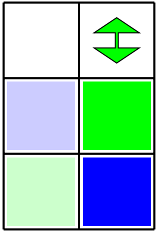

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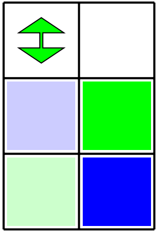

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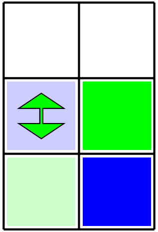

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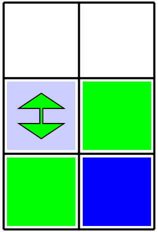

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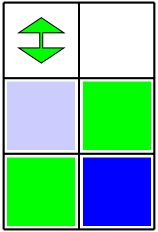

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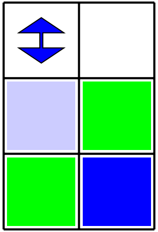

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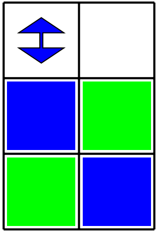

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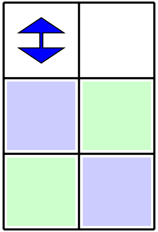
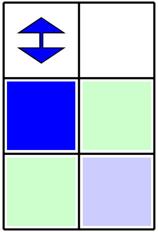
Example Domain: Floortile SIW Failure



(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_Φ: $\mathrm{SIW}_{R_\Phi} = \mathrm{SIW}$
- SIW traps into unsolvable state

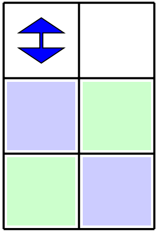
Example Domain: Floortile SIW Failure



(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_Φ: $\text{SIW}_{R_\Phi} = \text{SIW}$
- SIW traps into unsolvable state

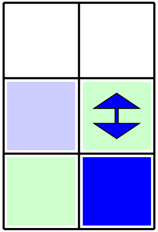
Example Domain: Floortile Sketch



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

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

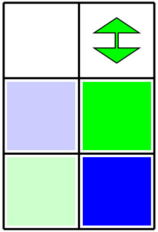
Example Domain: Floortile Sketch



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

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

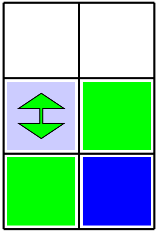
Example Domain: Floortile Sketch



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

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

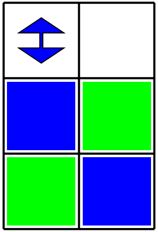
Example Domain: Floortile Sketch



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

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

Example Domain: Floortile Sketch



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

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

Example Domain: Barman Dynamics

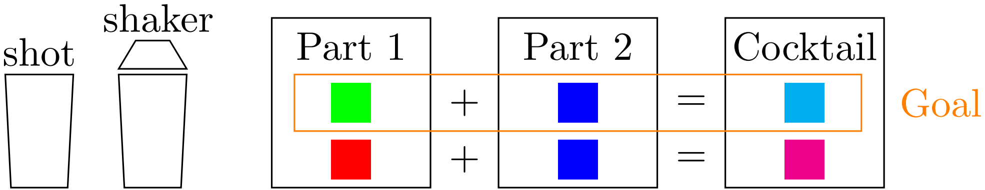
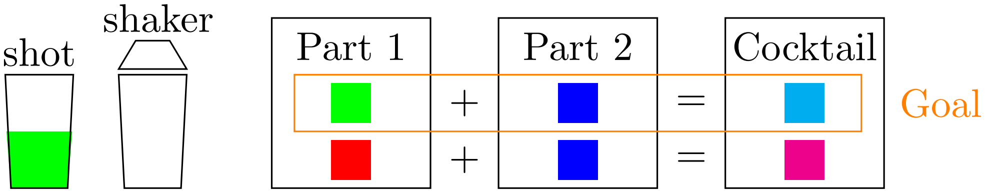


Figure: Plan execution

Example Domain: Barman Dynamics



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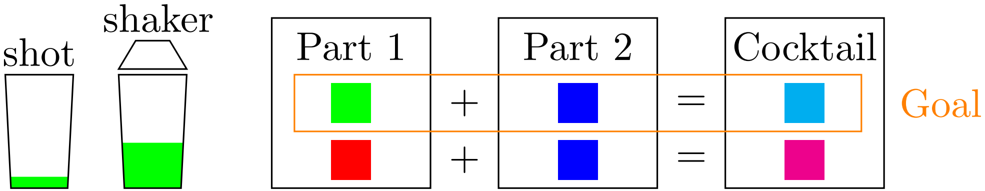

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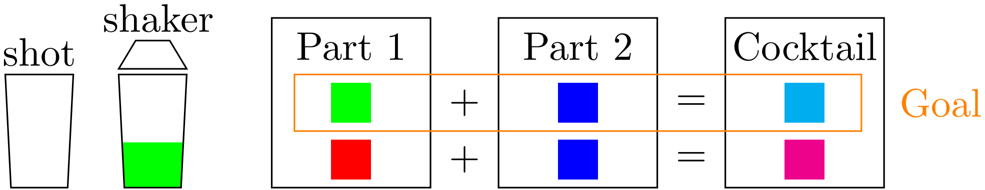

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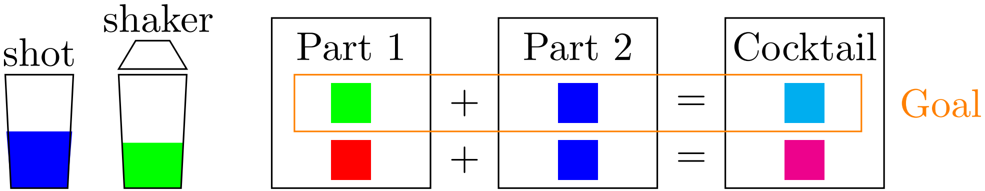

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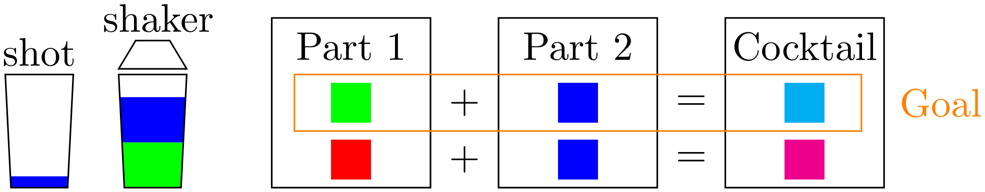

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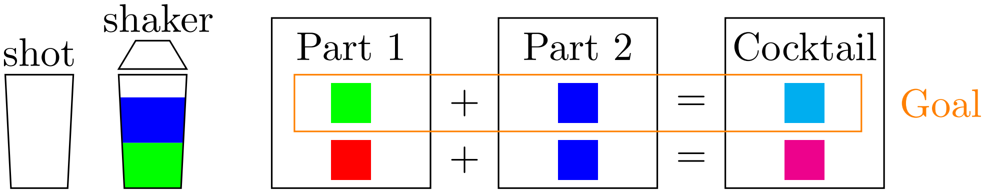

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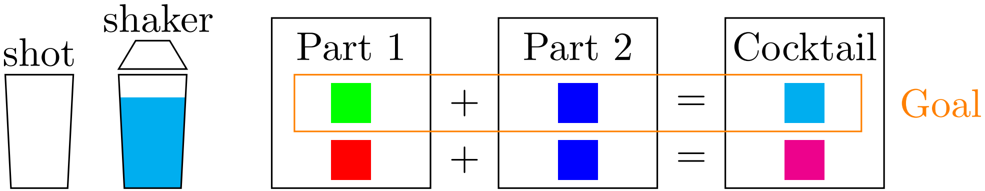

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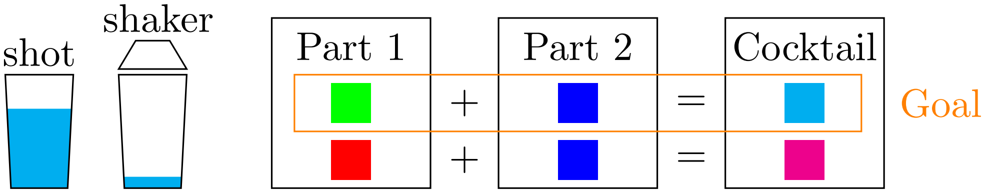

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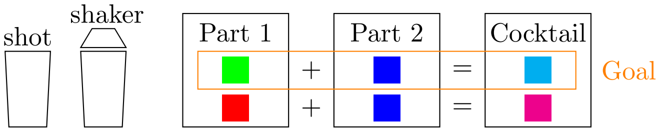

Figure: Initial state s_0

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \mathit{dirtyShots}, \mathit{Consistent}_1, \mathit{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

$$r_1 = \{\neg \mathit{Consistent}_1\} \mapsto \{\mathit{dirtyShots}?, \mathit{Consistent}_1\},$$

$$r_2 = \{\mathit{Consistent}_1, \neg \mathit{Consistent}_2\} \mapsto \{\mathit{dirtyShots}?, \mathit{Consistent}_2\},$$

$$r_3 = \{\mathit{dirtyShots} > 0\} \mapsto \{\mathit{dirtyShots}\downarrow\},$$

$$r_4 = \{\#g > 0\} \mapsto \{\#g\downarrow, \mathit{Consistent}_1?, \mathit{Consistent}_2?\}.$$

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

Example Domain: Barman

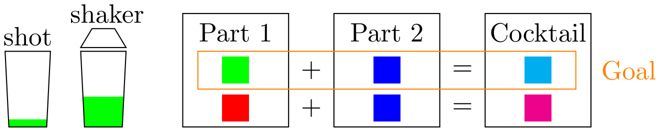

Figure: Rule r_1 leads to $s2$

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \mathit{dirtyShots}, \mathit{Consistent}_1, \mathit{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

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

Example Domain: Barman

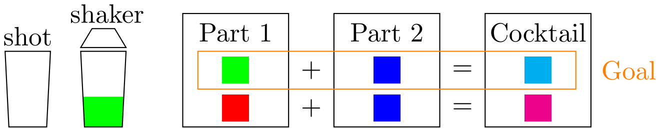

Figure: Rule r_3 leads to $s3$

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \mathit{dirtyShots}, \mathit{Consistent}_1, \mathit{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

$$r_1 = \{\neg \mathit{Consistent}_1\} \mapsto \{\mathit{dirtyShots}?, \mathit{Consistent}_1\},$$
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- **Theorem:** R_Φ terminates and $w_{R_\Phi}(Q) = 2$

Example Domain: Barman

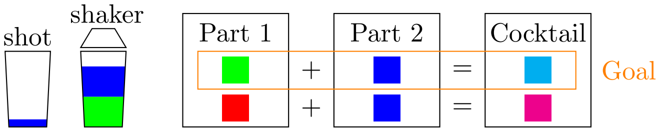

Figure: Rule r_2 leads to $s5$

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, dirtyShots, Consistent_1, Consistent_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

$$r_1 = \{\neg Consistent_1\} \mapsto \{dirtyShots?, Consistent_1\},$$
$$r_2 = \{Consistent_1, \neg Consistent_2\} \mapsto \{dirtyShots?, Consistent_2\},$$
$$r_3 = \{dirtyShots > 0\} \mapsto \{dirtyShots\downarrow\},$$
$$r_4 = \{\#g > 0\} \mapsto \{\#g\downarrow, Consistent_1?, Consistent_2?\}.$$

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

Example Domain: Barman

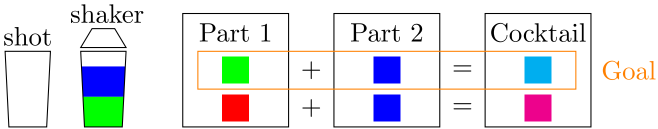

Figure: Rule r_3 leads to $s6$

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \mathit{dirtyShots}, \mathit{Consistent}_1, \mathit{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

$$r_1 = \{\neg \mathit{Consistent}_1\} \mapsto \{\mathit{dirtyShots}?, \mathit{Consistent}_1\},$$

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$$r_3 = \{\mathit{dirtyShots} > 0\} \mapsto \{\mathit{dirtyShots}\downarrow\},$$

$$r_4 = \{\#g > 0\} \mapsto \{\#g\downarrow, \mathit{Consistent}_1?, \mathit{Consistent}_2?\}.$$

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

Example Domain: Barman

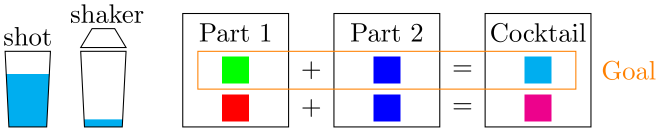

Figure: Rule r_4 leads to goal

- SIW fails because subproblem of serving cocktail has large width
- **Features** $\Phi = \{\#g, \mathit{dirtyShots}, \mathit{Consistent}_1, \mathit{Consistent}_2\}$
- **Sketch** $R_\Phi = \{r_1, r_2, r_3, r_4\}$

$$r_1 = \{\neg \mathit{Consistent}_1\} \mapsto \{\mathit{dirtyShots}?, \mathit{Consistent}_1\},$$
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- **Theorem:** R_Φ terminates and $w_{R_\Phi}(Q) = 2$

Experiments

	SIW(2)				$SIW_R(2)$				LAMA		Dual-BFWS	
Domain	S	T	AW	MW	S	T	AW	MW	S	T	S	T
Barman (40)	0	–	–	–	40	0.9	1.17	2	40	505.3	40	162.8
Childsnack (20)	0	–	–	–	20	10.8	1.00	1	6	2.6	8	216.9
Driverlog (20)	8	0.5	1.68	2	20	0.8	1.00	1	20	7.6	20	4.2
Floortile (20)	0	–	–	–	20	0.2	1.25	2	2	9.9	2	176.3
Grid (5)	1	0.1	2.00	2	5	0.1	1.00	1	5	3.6	5	3.7
Schedule (150)	62	1349.1	1.10	2	150	54.7	1.17	2	150	15.3	150	151.4
TPP (30)	11	74.7	2.00	2	30	0.4	1.00	1	30	16.5	29	99.6
# 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

Bonet, B. and Geffner, H. (2021).
General policies, representations, and planning width.
In *Proc. AAAI 2021*, pages 11764–11773.

Lipovetzky, N. and Geffner, H. (2012).
Width and serialization of classical planning problems.
In *Proc. ECAI 2012*, pages 540–545.