Decoupled Search for the Masses: A Novel Task Transformation for Classical Planning

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[1]Linköping University, Sweden

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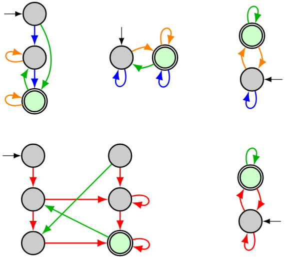
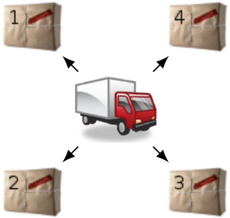
Motivation

We often transform our planning task to make an efficient search possible!

Factored Transition System



Decoupled Search



- ✔ Potentially exponentially more efficient
- ✔ Fully automated
- ✗ Alternative state representation $\rightsquigarrow$ Specialized search algorithms

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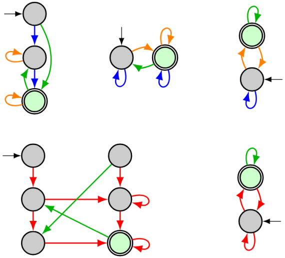

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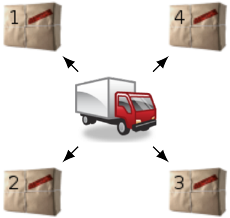

- ✔ Potentially exponentially more efficient
- ✔ Fully automated
- ✔ Task transformation ⇝ Standard search algorithms ?

Decoupled Search

Satisficing Planning

- Factoring $\mathcal{F} = \langle C, \mathcal{L} \rangle$ of vars $\mathcal{V}$
  - Based on causal structure
  - One center $C \subseteq \mathcal{V}$
  - Many leaves $\mathcal{L}$: $L_1, \ldots, L_n \subseteq \mathcal{V}$

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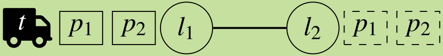

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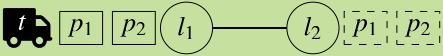

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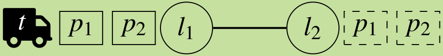

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$\mathcal{I}^{\mathcal{F}}$: $t = l_1$

	l_1	l_2	t
p_1	1	0	0
p_2	1	0	0

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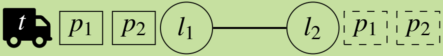

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saturate

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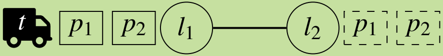

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saturate

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	l_1	l_2	t
p_1	1	0	0
p_2	1	0	0

$\mathcal{I}^{\mathcal{F}}_*$: $t = l_1$

	l_1	l_2	t
p_1	1	0	1
p_2	1	0	1

$s^{\mathcal{D}}$: $t = l_2$

	l_1	l_2	t
p_1	1	0	1
p_2	1	0	1

drive(l_1, l_2)

Decoupled Search

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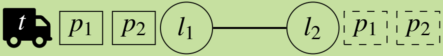

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$\mathcal{I}^{\mathcal{F}}$: $t = l_1$ —saturate→ $\mathcal{I}^{\mathcal{F}}_*$: $t = l_1$ —drive(l_1, l_2)→ $s^{\mathcal{D}}$: $t = l_2$ —saturate→ $s^{\mathcal{D}}_*$: $t = l_2$

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p_1	1	0	0
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$\mathcal{I}^{\mathcal{F}}_*$: $t = l_1$

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$s^{\mathcal{D}}$: $t = l_2$

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Decoupled Search as Task Transformation – Idea

$\boxed{\text{Input: SAS}^+ \text{ Planning Task } \Pi = \langle \mathcal{V}, \mathcal{I}, \mathcal{G}, \mathcal{O} \rangle}$

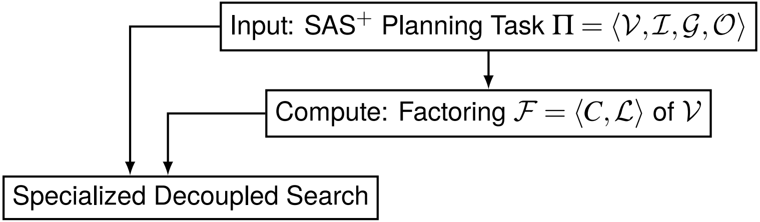
Decoupled Search as Task Transformation – Idea

$$\boxed{\text{Input: SAS}^{+} \text{ Planning Task } \Pi = \langle \mathcal{V}, \mathcal{I}, \mathcal{G}, \mathcal{O} \rangle}$$

$$\downarrow$$

$$\boxed{\text{Compute: Factoring } \mathcal{F} = \langle C, \mathcal{L} \rangle \text{ of } \mathcal{V}}$$

Decoupled Search as Task Transformation – Idea



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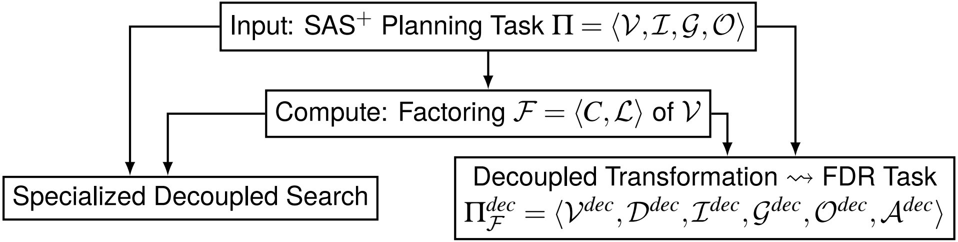

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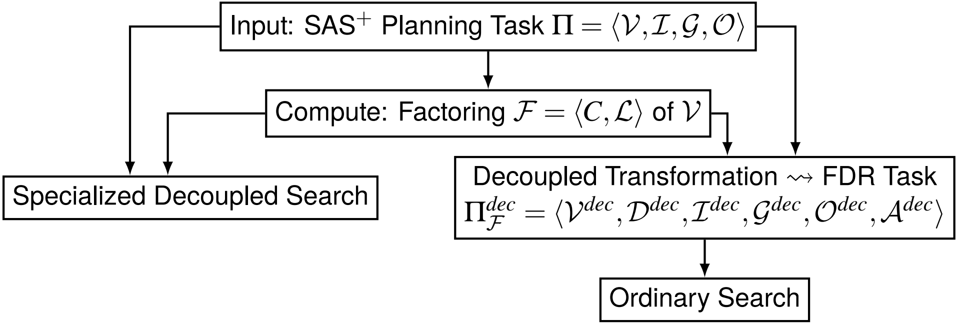

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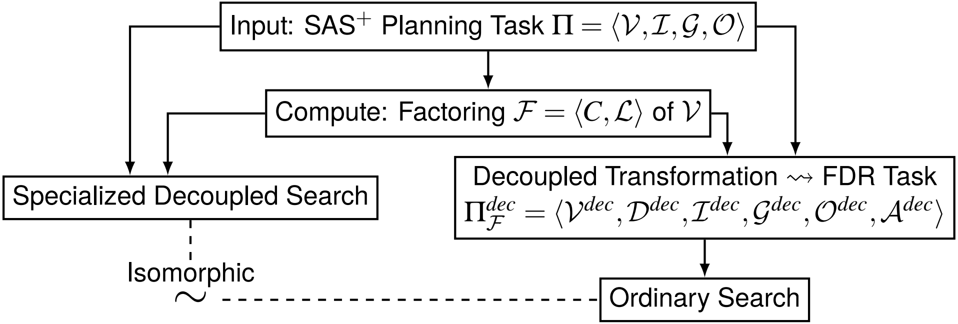

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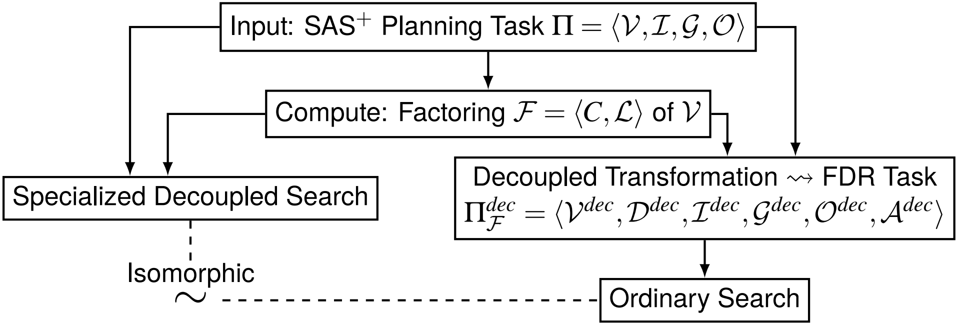


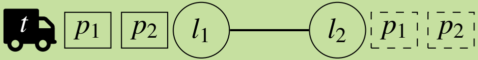
- Embodies decoupled search $\rightsquigarrow$ Potential exponentially smaller search space
- No specialized algorithms $\rightsquigarrow$ Past and future planning techniques work out of the box

Decoupled Transformation

Leaf dynamics $\rightsquigarrow$ Axioms!

Variables:

- $\mathcal{F} = \langle \{t\}, \{\{p_1\}, \{p_2\}\} \rangle$
- $\mathcal{V}^{dec}$: t and v_{s^L} for each leaf state
- $\mathcal{D}^{dec}$: d_{s^L} for each leaf state



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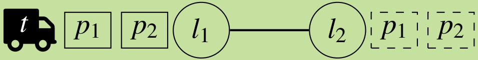

$\mathcal{A}(\mathcal{I}^{dec})$:

$\mathcal{I}^{dec}$: $t = l_1$

$v_{\{*\}}$	Val	$d_{\{*\}}$	Val
(p_1, l_1)	1	(p_1, l_1)	
(p_1, l_2)	0	(p_1, l_2)	
(p_1, t)	0	(p_1, t)	
(p_2, l_1)	1	(p_2, l_1)	
(p_2, l_2)	0	(p_2, l_2)	
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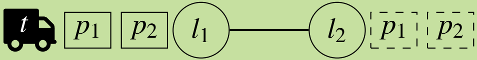

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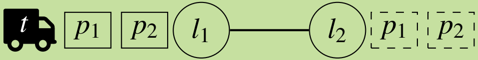

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(p_2, l_1)	1	(p_2, l_1)	1
(p_2, l_2)	0	(p_2, l_2)	0
(p_2, t)	0	(p_2, t)	0

extend

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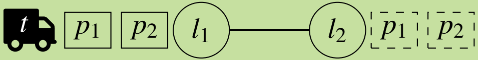

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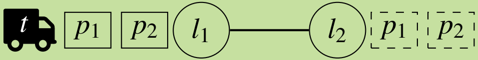
Operators

- drive



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extend

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Leaf dynamics ⇝ Axioms!

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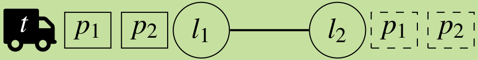
- drive



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(p_2, l_2)	0	(p_2, l_2)	0
(p_2, t)	0	(p_2, t)	1

$\mathcal{A}(s)$:

s: $t = l_2$

$v_{\{*\}}$	Val	$d_{\{*\}}$	Val
(p_1, l_1)	1	(p_1, l_1)	0
(p_1, l_2)	0	(p_1, l_2)	0
(p_1, t)	1	(p_1, t)	0
(p_2, l_1)	1	(p_2, l_1)	0
(p_2, l_2)	0	(p_2, l_2)	0
(p_2, t)	1	(p_2, t)	0

extend

drive(l_1, l_2)

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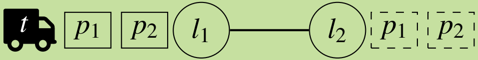

$\mathcal{A}(\mathcal{I}^{dec})$:

$\mathcal{I}^{dec}$: $t = l_1$

$v_{\{*\}}$	Val	$d_{\{*\}}$	Val
(p_1, l_1)	1	(p_1, l_1)	1
(p_1, l_2)	0	(p_1, l_2)	0
(p_1, t)	0	(p_1, t)	1
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extend

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extend

Decoupled Transformation

Leaf dynamics $\rightsquigarrow$ Axioms!

Variables:

- $\mathcal{F} = \langle \{t\}, \{\{p_1\}, \{p_2\}\} \rangle$
- $\mathcal{V}^{dec}$: t and v_{s^L} for each leaf state
- $\mathcal{D}^{dec}$: d_{s^L} for each leaf state

Axioms:

- Frame: $d_{s^L} \leftarrow v_{s^L}$
- Leaf-only ops: load & unload

Operators

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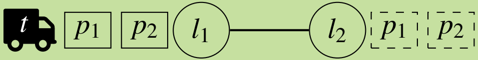

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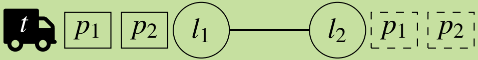

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Isomorphic State Spaces

- One-to-one mapping
  - $\rightsquigarrow$ Decoupled states $\rightleftarrows$ unextended states of $\Pi_{\mathcal{F}}^{dec}$
- Similar relationship
  - $\rightsquigarrow$ Saturated decoupled states $\rightleftarrows$ extended states of $\Pi_{\mathcal{F}}^{dec}$
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$\rightsquigarrow$ Search algorithms applied on $\Pi^{dec}_{\mathcal{F}}$ behave identically to specialized counterparts

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Optimizations and Related Work

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Related Work – Miura & Fukunaga (ICAPS 2017):

- Transforming a planning task into a more concise form using axioms

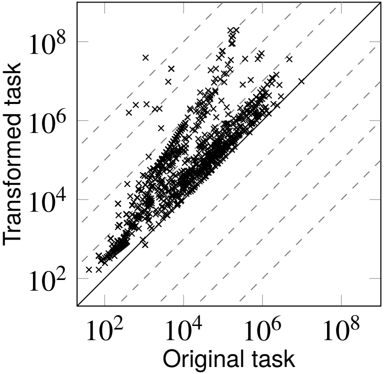
$\rightsquigarrow$ A weaker form of a single conclusive leaf

$\rightsquigarrow$ Special form of decoupled search

$\rightsquigarrow$ We generalize it in multiple dimensions!

Experiments – Size and Time of Transformation

Satisficing IPC Benchmark: 2106 tasks



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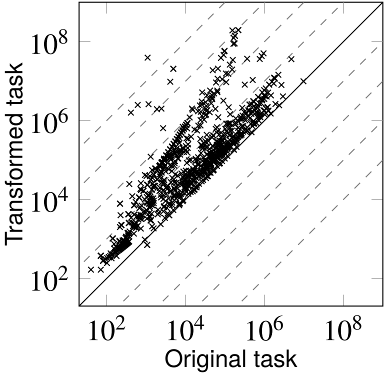

Time	<1s	<5s	<10s	<30s	<60s	≥60s	DNF
# Tasks	955	47	24	14	3	12	4

Experiments – Planning Performance

Satisficing IPC Benchmark: 2106 tasks

Domain		GBFS(h^{FF}, PO) *dec*	*sas*	*gh*	*ts*
airport		12	**14**	11	13
data-net		9	10	5	**11**
floortile11		14	8	**17**	8
nomystery		16	9	**19**	10
tetris		9	**14**	11	2
transport14		**20**	9	**20**	**20**
…			…		
Sum	1059	944	912	**980**	915

dec: Decoupled Transformation
sas: Original SAS$^+$ Task
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Domain	GBFS(h^{FF}, PO)				LAMA	
	dec	*sas*	*gh*	*ts*	*dec*	*sas*
airport	12	**14**	11	13	12	11
data-net	9	10	5	11	10	**13**
floortile11	14	8	17	8	**19**	7
nomystery	16	9	**19**	10	18	12
tetris	9	**14**	11	2	5	**14**
transport14	**20**	9	**20**	**20**	**20**	17
...	...				...	
Sum 1059	944	912	**980**	915	**962**	942

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Miura & Fukunaga Factoring (mf):

- Effective on 311 of 2106 tasks
  - $\rightsquigarrow$ Single conclusive leaf
- Same coverage as sas
- Max speed-up factor: 242

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Conclusions

Summary

- Novel task transformations mimicking decoupled search
- Encoding leaf dynamics of decoupled search as axioms
- Transformed task's state space $\overset{isomorphic}{\sim}$ Decoupled state space
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Full Paper

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Future Work

- Reduction of transformed task size: e.g., irrelevance pruning
- Preserve costs: optimal planning
- Other reduction techniques as task transformations: symmetry breaking, partial-order

References I

- Gnad, Daniel and Jörg Hoffmann (2018). “Star-Topology Decoupled State Space Search”. In: *AIJ* 257, pp. 24–60.
- Torralba, Álvaro and Silvan Sievers (2019). “Merge-and-Shrink Task Reformulation for Classical Planning”. In: *Proc. IJCAI 2019*, pp. 5644–5652.

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