Implementation and Evaluation of Search Strategies for Hybrid Planning

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Outline

Hybrid Planning

POCL Planning

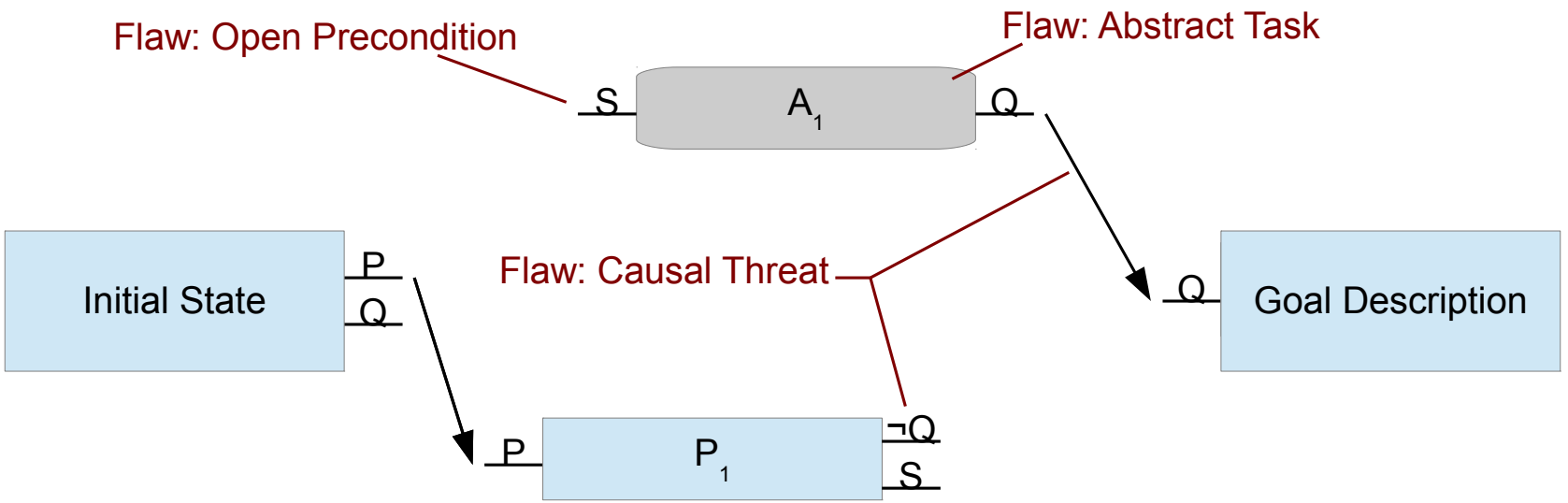
- Causal Reasoning
- Knowledge Rich Plans

Hierarchical Planning

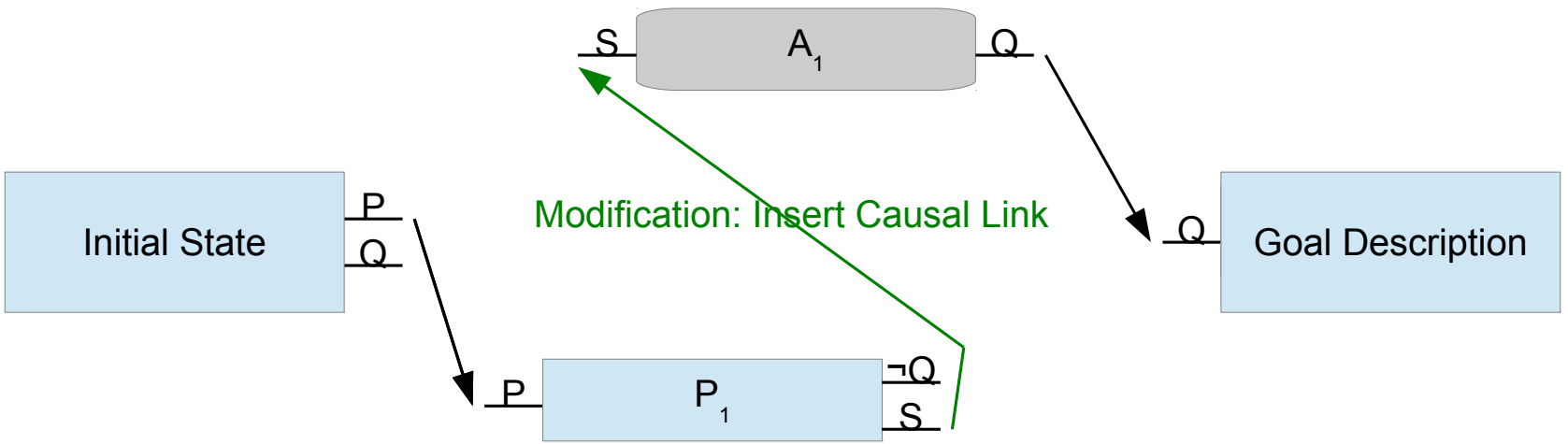
- Task Decomposition
- Similar to human planning

Hybrid Planning

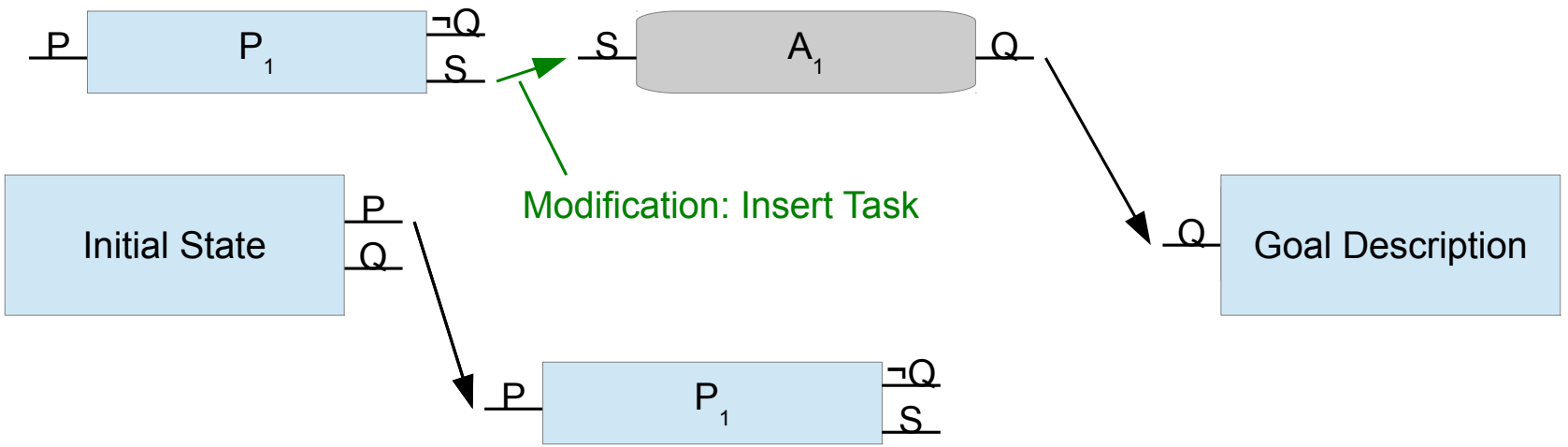
Example Plan



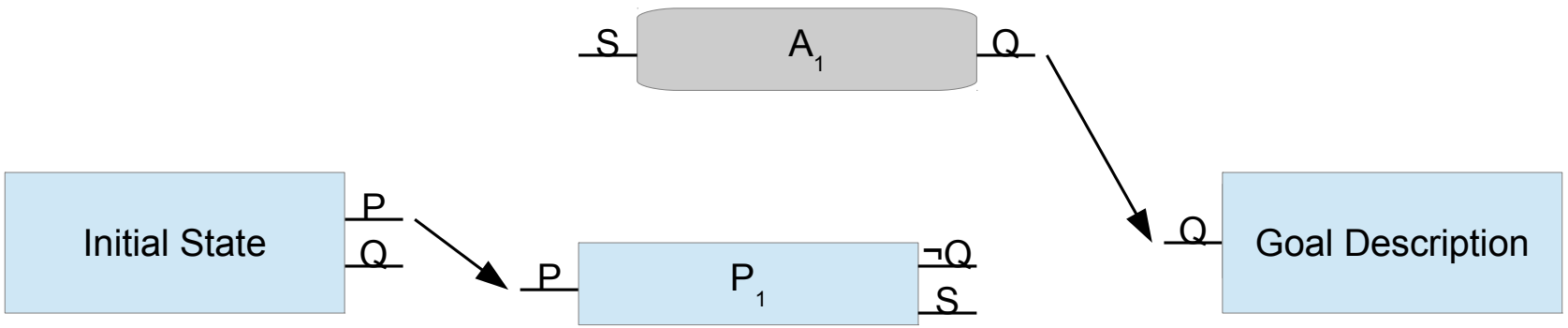
Address open precondition flaw S of task A_1 (possibility 1)



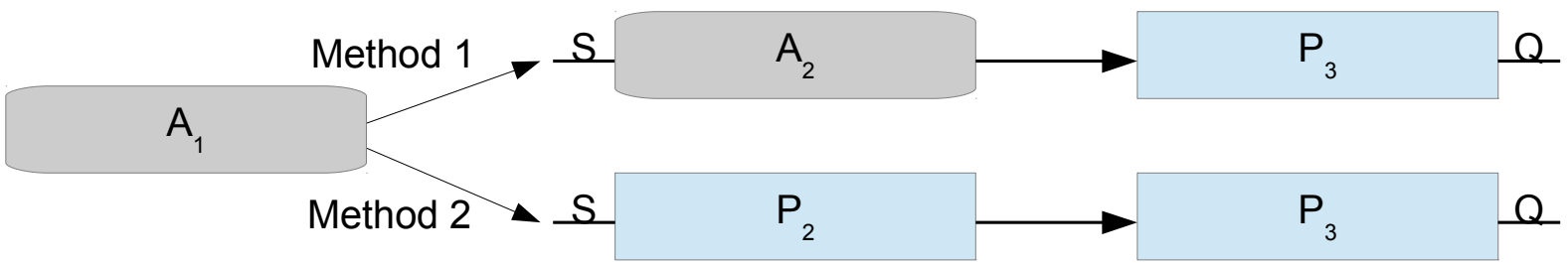
Address open precondition flaw S of task A_1 (possibility 2)



Address abstract task flaw A_1



Decomposition methods for A_1:



Motivation / Task of the Thesis

- The planning architecture PANDA solves hybrid planning problems
- PANDA$_2$ is a reimplementation with runtime improvements
- Main search procedure changed from PANDA to PANDA$_2$

$\Rightarrow$ implement and evaluate search strategies from PANDA to PANDA$_2$

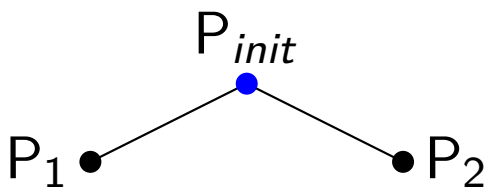
$\Rightarrow$ investigating the differences between PANDA and PANDA$_2$

Fringe$\{P_{init}\}$

blue: expanded
black: not expanded
red: solution

PANDA$_2$ Algorithm

Practical Approach



Fringe$\{P_1, P_2\}$

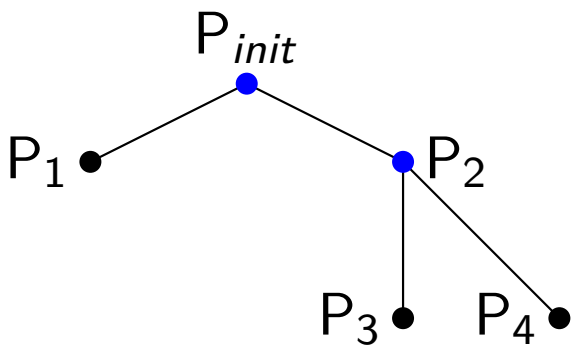
blue: expanded

black: not expanded

red: solution

PANDA$_2$ Algorithm

Practical Approach



Fringe$\{P_1, P_3, P_4\}$

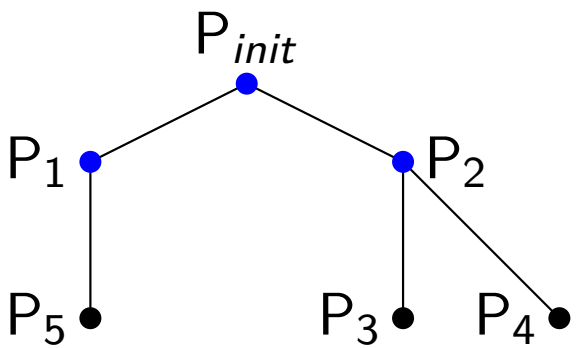
blue: expanded

black: not expanded

red: solution

PANDA$_2$ Algorithm

Practical Approach

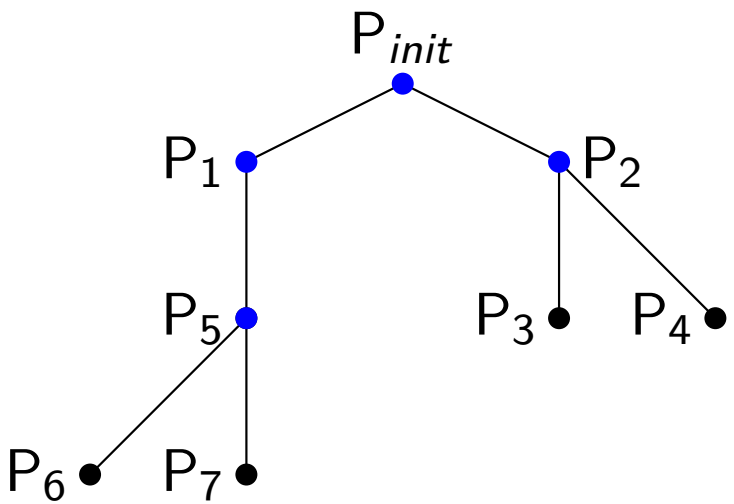


Fringe$\{P_3, P_4, P_5\}$

blue: expanded

black: not expanded

red: solution

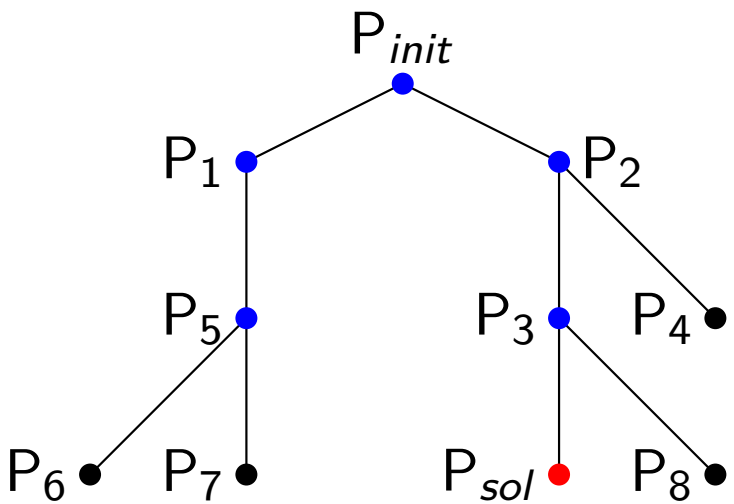


Fringe$\{P_3, P_4, P_6, P_7\}$

blue: expanded

black: not expanded

red: solution



Fringe$\{P_{sol}, P_4, P_6, P_7, P_8\}$

blue: expanded

black: not expanded

red: solution

PANDA$_2$ Algorithm

Algorithm 1: PANDA$_2$ planning procedure

1 $Fringe \leftarrow \{P_{init}\}$
2 **while** $Fringe \neq \emptyset$ **do**
3 $\quad P \leftarrow$ `planSel` $(Fringe)$
4 $\quad Fringe \leftarrow Fringe \setminus \{P\}$
5 $\quad$ **if** $Flaws(P) = \emptyset$ **then return** P
6 $\quad f \leftarrow$ `flawSel` $(Flaws(P))$
7 $\quad Fringe \leftarrow Fringe \cup \{$ `applyMod`$(P, m) \mid m \in Mods(f)\}$
8 **return** *fail*

Plan selection:

- first decision point of the algorithm
- decides which plan to develop further

Which plan to refine first, P_i or P_j?

$$P_i < P_j \in f^{\text{PlanSel}}_{CL+OCA}(\{P_1, \ldots, P_n\}) \text{ if:}$$
$$\frac{|CL_i| + |flaws(P_i) \cap (\mathbb{F}_{OpenPrec} \cup \mathbb{F}_{AbstrTask})|}{|CL_j| + |flaws(P_j) \cap (\mathbb{F}_{OpenPrec} \cup \mathbb{F}_{AbstrTask})|} < 1$$

A Plan is a Tupel $P = \langle PS, \prec, VC, CL \rangle$

- $PS =$ plan steps of the plan
- $\prec =$ ordering constraints
- $VC =$ variable constraints
- $CL =$ causal links

Which plan to refine first, P_i or P_j?

$$P_i < P_j \in f^{\text{PlanSel}}_{ConstrPlans}(\{P_1, \ldots, P_n\}) \text{ if:}$$
$$\frac{|\prec_i| + |VC_i| + |CL_i|}{|PS_i|} > \frac{|\prec_j| + |VC_j| + |CL_j|}{|PS_j|}$$

Which plan to refine first, P_i or P_j?

$$P_i < P_j \in f^{\text{PlanSel}}_{DirUniHs}(\{P_1, \ldots, P_n\}) \text{ if:}$$

$$\frac{\sum_{f \in flaws(P_i)} \sum_{f' \in flaws(P_i) \setminus \{f\}} |f \cap f'|}{|flaws(P_i)|} < \frac{\sum_{f \in flaws(P_j)} \sum_{f' \in flaws(P_j) \setminus \{f\}} |f \cap f'|}{|flaws(P_j)|}$$

$f_1 = \{ps_a, \phi_a\}$, $f_2 = \{ps_b, \phi_b\}$ = open precondition flaws
$f_3 = \{ps_a\}$ = abstract task Flaw

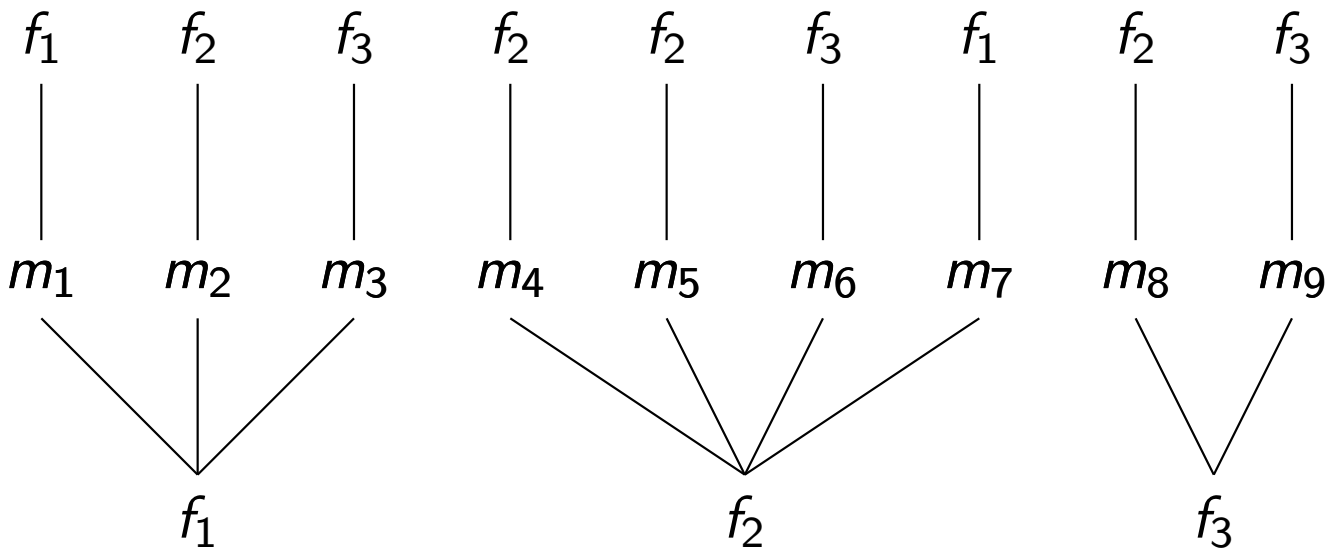
Flaw selection:

- second decision point of the algorithm
- decides which flaw should be resolved

Problem:

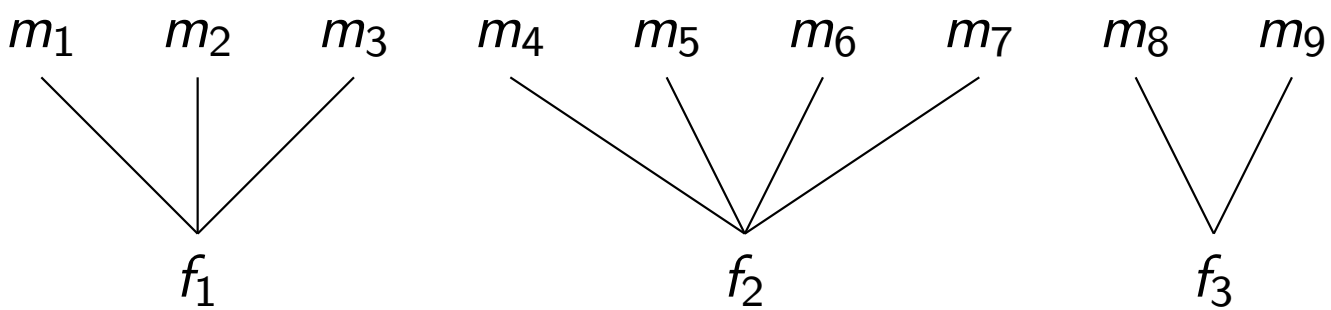
- PANDA orders Modifications of *all* Flaws
- PANDA_2 selects *one* Flaw

Modification ordering in PANDA:
Let a plan P have the flaws f_1, f_2, f_3



Which flaw to resolve first, f_i or f_j?

$$f_i < f_j \in f_{LCFR}^{\text{FlawSel}}(\{f_1, \ldots, f_n\}) \text{ if}$$
$$|modsFor(f_i)| < |modsFor(f_j)|$$



Which flaw to resolve first, f_i or f_j?

$$f_i < f_j \in f^{\mathsf{FlawSel}}_{DirUniHS}(\{f_1, \ldots, f_n\}) \text{ if } \sum_{f \in (\{f_1,\ldots,f_m\} \setminus \{f_i\})} |f \cap f_i| < \sum_{f \in (\{f_1,\ldots,f_m\} \setminus \{f_j\})} |f \cap f_j|$$

Evaluation

Overview

The evaluation should answer the following questions:

- Which strategy combination solved the most Problems?
- Which strategy combination generates a solution most quickly? (efficiency)

Domains:

- Satellite with 5 Problems
- Smartphone with 2 Problems
- UM-Translog with 12 Problems

17 Plan Selection Strategy Combinations and 12 Flaw Selection Strategy Combinations which were run 5 times per Combination.
$\rightarrow$ 17*12*5 = 1020 runs per Problem

Evaluation

Table of Combinations

Plan Selectors	**Flaw Selector**
Primary	**Primary**
CL+OCA	EMS
Direct-Uniform-Hotspot	LCFR
Indirect-Uniform-Hotspot	**Secondary**
ConstrPlans	LCFR
ConstrPlans^{-1}	Direct Uniform Hotspot
PSA+OCA	Indirect Uniform Hotspot
$\mathbb{F}$/PS	Direct Adaptive Hotspot
Secondary	Indirect Adaptive Hotspot
Fewer-$\mathbb{M}$	EMS
ConstrPlans	$f^{\text{FlawSel}}_{Addr-\mathbb{F}_{AbstrTask}}$
ConstrPlans^{-1}	

2 kinds of Tables:

- percentage of solved problems
- average efficiency

For each of these kinds 4 tables have been made:

- Smartphone Domain
- Satellite Domain
- UM-Translog
- All Domains combined

Evaluation

Example: Percentage of Solved Problems over all Domains

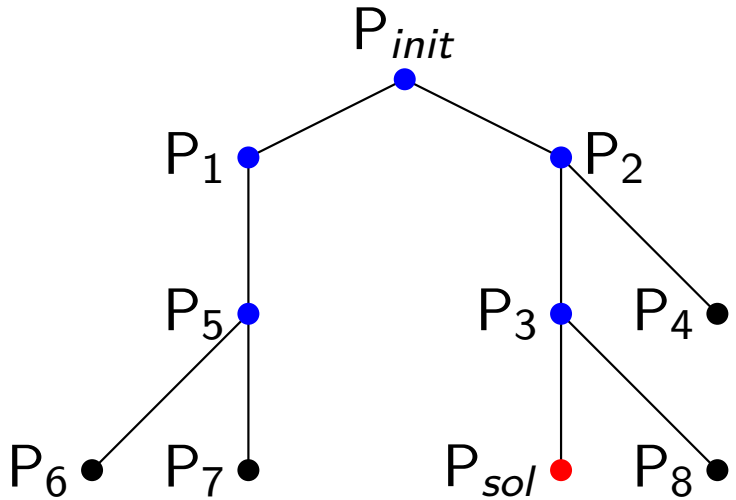
		CL+OCA	CP	CP^{-1}	DUHS	F/TE	IUHS	PSA+OCA
1	EMS	89.47	89.47	92.63	89.82	95.09	89.47	89.47
2	EMS,DAHS	89.47	89.47	92.63	90.53	94.74	89.47	89.47
3	EMS,DUHS	89.47	89.47	90.53	89.12	94.74	89.47	89.47
4	EMS,IAHS	89.47	89.47	97.89	92.63	95.09	92.63	89.47
5	EMS,IUHS	89.47	89.47	97.89	91.58	94.04	89.82	89.47
6	EMS,LCFR	89.47	89.47	95.79	90.18	94.39	89.47	89.47
7	LCFR,Abstract	100.00	94.74	94.74	95.09	95.44	94.74	100.00
8	LCFR,DAHS	100.00	94.74	94.74	95.44	94.74	96.49	100.00
9	LCFR,DUHS	100.00	94.74	94.74	94.74	94.74	95.79	100.00
10	LCFR,EMS	100.00	94.74	94.74	95.09	94.74	94.74	100.00
11	LCFR,IAHS	100.00	94.74	94.74	95.79	94.74	94.74	100.00
12	LCFR,IUHS	100.00	94.74	94.74	95.09	94.74	94.74	100.00

Evaluation

Example: Percentage of Solved Problems over all Domains

		CL+OCA	CP	CP^{-1}	DUHS	F/TE	IUHS	PSA+OCA
1	EMS	89.47	89.47	92.63	89.82	95.09	89.47	89.47
2	EMS,DAHS	89.47	89.47	92.63	90.53	94.74	89.47	89.47
3	EMS,DUHS	89.47	89.47	90.53	89.12	94.74	89.47	89.47
4	EMS,IAHS	89.47	89.47	97.89	92.63	95.09	92.63	89.47
5	EMS,IUHS	89.47	89.47	97.89	91.58	94.04	89.82	89.47
6	EMS,LCFR	89.47	89.47	95.79	90.18	94.39	89.47	89.47
7	LCFR,Abstract	100.00	94.74	94.74	95.09	95.44	94.74	100.00
8	LCFR,DAHS	100.00	94.74	94.74	95.44	94.74	96.49	100.00
9	LCFR,DUHS	100.00	94.74	94.74	94.74	94.74	95.79	100.00
10	LCFR,EMS	100.00	94.74	94.74	95.09	94.74	94.74	100.00
11	LCFR,IAHS	100.00	94.74	94.74	95.79	94.74	94.74	100.00
12	LCFR,IUHS	100.00	94.74	94.74	95.09	94.74	94.74	100.00

The efficiency value is the number of expanded plans divided by the length of the path to the solution.



blue: expanded

black: not expanded

red: solution

necessary expansions: 4

actual expansions: 6 $\rightarrow$ efficiency: $\frac{4}{6} = 66\%$

Evaluation

Example: average Efficiency over all Domains

		CL+OCA	CP	CP^{-1}	DUHS	F/TE	IUHS	PSA+OCA
1	EMS	16.54	20.73	74.16	32.45	56.94	30.73	31.41
2	EMS,DAHS	16.33	20.33	71.45	25.38	59.88	26.64	28.00
3	EMS,DUHS	16.42	20.55	72.46	26.80	59.82	27.37	27.62
4	EMS,IAHS	17.12	19.18	68.79	26.84	57.35	28.14	27.34
5	EMS,IUHS	17.16	19.56	69.18	25.43	57.75	28.61	27.39
6	EMS,LCFR	19.06	22.87	72.88	34.34	49.81	36.42	32.92
7	LCFR,Abstract	63.16	66.83	78.36	75.62	77.31	73.29	70.44
8	LCFR,DAHS	60.99	65.62	78.53	75.56	76.98	70.20	69.80
9	LCFR,DUHS	61.89	66.93	77.44	77.75	77.04	71.46	69.50
10	LCFR,EMS	60.09	64.66	81.29	75.47	75.13	71.23	69.33
11	LCFR,IAHS	62.30	66.92	77.53	75.27	77.72	72.44	70.46
12	LCFR,IUHS	61.97	66.92	77.69	77.58	76.33	72.37	68.20

Conclusion

- Differences between PANDA and PANDA$_2$ have been analyzed.
- Search-Strategies of PANDA have been transferred to PANDA$_2$.
- A Evaluation has been done, with some interesting findings.
  - PSA+OCA as primary plan selection and LCFR as primary flaw selection
  - CL+OCA as primary plan selection and LCFR as primary flaw selection

PANDA Algorithm

Algorithm 2: PANDA planning procedure

1 $Fringe \leftarrow \langle P_{init} \rangle$
2 **while** $Fringe \neq \emptyset$ **do**
3 $\quad P \leftarrow P_1$
4 $\quad$ **if** $Flaws(P) = \emptyset$ **then return** P
5 $\quad F = Flaws(P)$
6 $\quad \langle m_1 \dots m_i \rangle = \text{ModOrd}(\cup_{f \in F} \text{mods(f)})$
7 $\quad Fringe = \text{PlanOrd}(\langle app(P_1, m_1) \dots app(P_1, m_i) \rangle \circ \langle P_2 \dots P_n \rangle)$
8 **return** *fail*

Differences between PANDA and PANDA$_2$

PANDA

- Addresses all flaws
- Order of plans depends on PlanOrd and ModOrd

PANDA$_2$

- Addresses just one flaw
- Order of plans depends only on PlanOrd

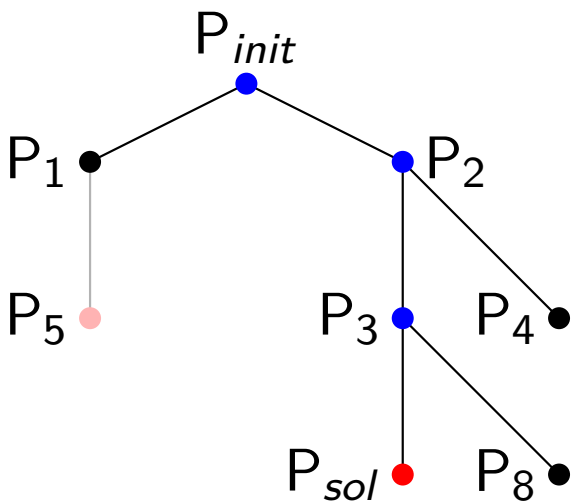
Which plan to refine first, P_i or P_j?

$$P_i < P_j \in f^{\text{PlanSel}}_{PSA+OCA}(\{P_1, \ldots, P_n\}) \text{ if:}$$
$$\frac{|psa(P_i)| + |flaws(P_i) \cap (\mathbb{F}_{OpenPrec} \cup \mathbb{F}_{AbstrTask})|}{|psa(P_j)| + |flaws(P_j) \cap (\mathbb{F}_{OpenPrec} \cup \mathbb{F}_{AbstrTask})|} < 1$$

psa(P) = returns the number of modifications, which led to this plan and inserted a Plan Step.

Efficiency Value

Not found solution



blue: expanded

black: not expanded

red: solution

Evaluation

Example: Percentage of Solved Problems in the UM-Translog Domain

		CL+OCA	CP	CP^{-1}	DUHS	F/PS	IUHS	PSA+OCA
1	EMS	91.67	91.67	95.00	91.67	100.00	91.67	91.67
2	EMS,DAHS	91.67	91.67	96.67	93.33	100.00	91.67	91.67
3	EMS,DUHS	91.67	91.67	93.33	92.22	100.00	91.67	91.67
4	EMS,IAHS	91.67	91.67	96.67	94.44	99.44	91.67	91.67
5	EMS,IUHS	91.67	91.67	96.67	92.78	98.89	91.67	91.67
6	EMS,LCFR	91.67	91.67	95.00	91.67	99.44	91.67	91.67
7	LCFR,Abstract	100.00	100.00	100.00	100.00	100.00	100.00	100.00
8	LCFR,DAHS	100.00	100.00	100.00	100.00	100.00	100.00	100.00
9	LCFR,DUHS	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10	LCFR,EMS	100.00	100.00	100.00	100.00	100.00	100.00	100.00
11	LCFR,IAHS	100.00	100.00	100.00	100.00	100.00	100.00	100.00
12	LCFR,IUHS	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Evaluation

Example: Percentage of Solved Problems in the Smartphone Domain

		CL+OCA	CP	CP^{-1}	DUHS	F/PS	IUHS	PSA+OCA
1	EMS	50.00	50.00	60.00	53.33	53.33	50.00	50.00
2	EMS,DAHS	50.00	50.00	50.00	50.00	50.00	50.00	50.00
3	EMS,DUHS	50.00	50.00	50.00	50.00	50.00	50.00	50.00
4	EMS,IAHS	50.00	50.00	100.00	63.33	56.67	80.00	50.00
5	EMS,IUHS	50.00	50.00	100.00	66.67	50.00	53.33	50.00
6	EMS,LCFR	50.00	50.00	90.00	56.67	50.00	50.00	50.00
7	LCFR,Abstract	100.00	50.00	50.00	53.33	56.67	50.00	100.00
8	LCFR,DAHS	100.00	50.00	50.00	56.67	50.00	66.67	100.00
9	LCFR,DUHS	100.00	50.00	50.00	50.00	50.00	60.00	100.00
10	LCFR,EMS	100.00	50.00	50.00	53.33	50.00	50.00	100.00
11	LCFR,IAHS	100.00	50.00	50.00	60.00	50.00	50.00	100.00
12	LCFR,IUHS	100.00	50.00	50.00	53.33	50.00	50.00	100.00

Evaluation

Example: average Efficiency in the Satellite Domain

		CL+OCA	CP	CP^{-1}	DUHS	F/PS	IUHS	PSA+OCA
1	EMS	9.13	8.81	30.32	21.31	16.66	14.65	16.78
2	EMS,DAHS	5.88	5.07	26.23	5.90	7.36	5.68	6.50
3	EMS,DUHS	6.23	5.51	27.12	6.36	7.05	7.78	5.43
4	EMS,IAHS	6.05	5.36	24.23	9.46	7.09	7.78	6.47
5	EMS,IUHS	6.25	5.91	22.78	6.28	7.11	7.79	5.37
6	EMS,LCFR	8.80	7.92	36.51	19.72	20.10	17.73	20.45
7	LCFR,Abstract	16.46	11.39	41.45	28.21	32.62	23.09	29.93
8	LCFR,DAHS	12.68	9.76	41.04	30.79	29.73	21.77	26.94
9	LCFR,DUHS	12.86	9.49	41.22	36.19	29.92	22.21	26.10
10	LCFR,EMS	11.49	8.97	52.37	29.84	23.88	20.83	25.88
11	LCFR,IAHS	14.80	10.00	41.08	28.49	32.53	23.11	29.64
12	LCFR,IUHS	11.59	9.47	40.53	36.23	27.83	22.19	21.25

Evaluation

Example: average Efficiency in the UM-Translog Domain

		CL+OCA	CP	CP^{-1}	DUHS	F/PS	IUHS	PSA+OCA
1	EMS	21.23	27.99	91.01	35.85	71.62	34.52	33.66
2	EMS,DAHS	22.36	29.08	88.49	31.25	79.69	34.33	32.44
3	EMS,DUHS	22.29	29.21	90.24	32.49	79.73	34.24	32.35
4	EMS,IAHS	23.50	27.16	88.38	31.31	76.80	35.63	31.53
5	EMS,IUHS	23.45	27.50	88.53	30.99	76.93	35.28	32.11
6	EMS,LCFR	25.13	31.66	88.40	40.05	59.40	40.92	34.30
7	LCFR,Abstract	85.97	90.26	91.94	94.34	94.78	92.65	91.13
8	LCFR,DAHS	85.88	90.51	92.35	94.58	94.75	92.52	91.22
9	LCFR,DUHS	85.80	90.97	90.65	94.82	94.76	92.28	91.06
10	LCFR,EMS	86.03	90.38	91.78	94.24	94.75	92.42	90.92
11	LCFR,IAHS	85.98	90.91	90.84	95.00	94.69	92.55	91.19
12	LCFR,IUHS	86.45	90.96	91.31	94.97	94.56	92.50	91.00

Evaluation

Example: average Efficiency in the Smartphone Domain

		CL+OCA	CP	CP^{-1}	DUHS	F/PS	IUHS	PSA+OCA
1	EMS	2.05	0.46	96.86	49.57	80.56	69.35	79.85
2	EMS,DAHS	2.19	0.39	100.00	57.03	84.82	46.80	86.59
3	EMS,DUHS	2.75	0.46	100.00	63.27	84.82	49.64	86.59
4	EMS,IAHS	2.30	0.53	66.63	55.42	74.23	40.29	85.56
5	EMS,IUHS	2.51	0.45	72.97	49.85	83.38	57.32	85.56
6	EMS,LCFR	3.57	0.88	75.60	43.42	83.80	80.31	80.05
7	LCFR,Abstract	43.00	62.96	100.00	87.20	89.58	91.90	47.59
8	LCFR,DAHS	32.41	46.20	100.00	71.62	100.00	50.97	48.41
9	LCFR,DUHS	41.02	65.62	100.00	80.77	100.00	68.48	48.61
10	LCFR,EMS	25.96	34.48	100.00	78.28	96.00	69.00	48.38
11	LCFR,IAHS	38.97	63.68	100.00	72.86	100.00	77.73	48.10
12	LCFR,IUHS	41.02	65.62	100.00	75.78	100.00	81.82	48.77

todo:

- definitionen der anderen strategien aus der tabelle in den Anhang
- abstände in der tabelle springen warum?