Type-WA*: Exploration in Bounded Suboptimal Planning (IJCAI-2021 Supplementary Material)

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This technical report provides additional experimental results for the paper "Type-WA*: Using Exploration in Bounded Suboptimal Planning". In our experiments we use the following three heuristics:

1. The merge-and-shrink heuristic (h^{MS}). Following the recommended configuration in FastDownward, we use a merge strategy that is based on the strongly connected components (SCCs) of the causal graph and a shrink strategy that is based on bisimulation.
2. The admissible variant of the landmark count heuristic (h^{LM}).
3. The landmark cut heuristic (h^{LC}).

A Detailed Results for Blocksworld

In Blocksworld, a robot arm needs to re-assemble stackable blocks on a table with unlimited space. The robot arm can be used for stacking a block onto a block, unstacking a block from a block, putting down a block, or picking up a block.

Table 1 reports the coverage (out of 100) for different weights for both h^{LM} and h^{LC}. Figure 1 and Figure 2 compare WA* and a single run of Type-WA* for h^{LM} based on solution time and expanded nodes, respectively. Figure 3 and Figure 4 show a similar comparison for h^{LC}.

	h^{LM}	
w	WA*	TWA*
1.5	74	**92.0**
2	87	**99.8**
3	98	**100.0**

	h^{LC}	
w	WA*	TWA*
1.3	84	**96.2**
1.5	93	**99.8**
2	**100**	**100.0**

Table 1: Number of solved Blocksworld instances (out of 100).

Figure 1: Time (seconds) on Blocksworld instances when using h^{LM}

Figure 2: Expanded nodes on Blocksworld instances when using h^{LM}

Figure 3: Time (seconds) on Blocksworld instances when using h^{LC}

Figure 4: Expanded nodes on Blocksworld instances when using h^{LC}

B Detailed Results for NoMystery

In NoMystery, the goal is to transport packages between different locations using a set of trucks with limited fuel.

Table 2 reports the coverage (out of 100) for different weights for both h^{MS} and h^{LM}. Figure 5 and Figure 6 compare WA* and a single run of Type-WA* for h^{MS} based on solution time and expanded nodes, respectively. Figure 7 and Figure 8 show a similar comparison for h^{LM}.

	h^{MS}		h^{LM}	
w	WA*	TWA*	WA*	TWA*
1.5	**100**	**100.0**	**100**	**100.0**
2	93	**100.0**	94	**100.0**
3	49	**100.0**	76	**100.0**
5	21	**100.0**	64	**100.0**

Table 2: Number of solved NoMystery instances (out of 100).

Figure 5: Time (seconds) on NoMystery instances when using h^{MS}

Figure 6: Expanded nodes on NoMystery instances when using h^{MS}

Figure 7: Time (seconds) on NoMystery instances when using h^{LM}

Figure 8: Expanded nodes on NoMystery instances when using h^{LM}

C Detailed Results for Different Weights

Table 3 shows the coverage for h^{MS} for $w \in \{2, 3, 10\}$. We find that Type-WA* has a significant gain in coverage even for lower and higher weights.

		$w = 2$		$w = 3$		$w = 10$	
Domain	#	WA*	TWA*	WA*	TWA*	WA*	TWA*
14-barman	14	1	**3.0**	3	**6.0**	6	**8.2**
14-cavediving	20	7	7.0	7	7.0	7	7.0
14-childsnack	20	0	**2.0**	0	**4.4**	5	4.8
14-citycar	20	15	**17.4**	15	**18.2**	16	**18.2**
14-floortile	20	**9**	8.0	6	5.2	2	2.0
14-ged	20	19	**20.0**	20	20.0	20	20.0
14-hiking	20	16	**19.0**	20	20.0	20	20.0
14-maintenance	5	5	5.0	5	5.0	5	5.0
14-openstacks	20	**3**	2.0	**3**	2.0	**3**	1.0
14-parking	20	8	**16.0**	13	12.4	16	16.0
14-tetris	17	7	7.0	7	7.0	7	7.0
14-tidybot	20	7	**12.4**	7	**15.8**	7	**17.6**
14-transport	20	7	**10.0**	7	**13.8**	7	**14.8**
14-visitall	20	5	**7.8**	6	**9.0**	9	**12.0**
18-agricola	20	0	**18.2**	0	**20.0**	1	**20.0**
18-caldera	20	10	**15.6**	10	**16.6**	10	**16.0**
18-data-net.	20	12	**16.0**	11	**18.0**	13	**19.8**
18-nurikabe	20	11	**12.0**	11	**14.0**	12	**15.0**
18-organic-syn.	20	7	7.0	7	7.0	7	7.0
18-petri-net.	20	**4**	3.0	**4**	3.0	4	**11.6**
18-settlers	20	8	**9.8**	8	**11.8**	11	11.2
18-snake	20	11	**14.0**	11	**14.8**	11	**19.8**
18-spider	20	11	**12.0**	11	**12.0**	12	12.0
18-termes	20	**13**	12.0	**15**	12.0	**16**	11.8
Total	456	196	**256.2**	207	**275.0**	227	**297.8**

Table 3: Number of solved instances in IPC domains using h^{MS} for different w values. TWA* is averaged over five runs. For each domain and heuristic, we highlight in bold the best result if the difference is greater or equal to 1.0.

D Detailed Results on Solution Cost and Exploration

Table 4 shows the normalized cost per domain for h^{MS} with $w \in \{2, 3, 10\}$. Recall that the normalized cost is averaged over solved instances only. The number of solved instances per domain can be found in the paper in Table 3.

	$w = 2$		$w = 3$		$w = 10$	
Domain	WA*	TWA*	WA*	TWA*	WA*	TWA*
14-barman	1.00	1.02	1.00	1.06	1.15	1.21
14-cavediving	1.00	1.01	1.00	1.01	1.00	1.01
14-childsnack	N/A	1.00	N/A	1.15	1.19	1.20
14-citycar	1.00	1.11	1.00	1.31	1.03	1.76
14-floortile	1.00	1.12	1.28	1.37	1.52	1.44
14-ged	1.00	1.04	1.00	1.13	1.00	1.54
14-hiking	1.05	1.10	1.05	1.13	1.20	1.22
14-maintenance	1.00	1.00	1.00	1.00	1.00	1.00
14-openstacks	1.00	1.00	1.00	1.00	1.00	1.00
14-parking	1.03	1.15	1.15	1.31	1.51	1.66
14-tetris	1.00	1.18	1.01	1.37	1.01	2.15
14-tidybot	1.00	1.28	1.00	1.64	1.00	4.21
14-transport	1.00	1.06	1.00	1.12	1.06	1.64
14-visitall	1.07	1.06	1.04	1.16	1.15	1.45
18-agricola	N/A	1.06	N/A	1.22	1.00	1.48
18-caldera	1.00	1.10	1.00	1.16	1.01	1.15
18-data-network	1.02	1.16	1.05	1.32	1.09	1.82
18-nurikabe	1.01	1.07	1.02	1.14	1.05	1.27
18-organic-synthesis	1.00	1.00	1.00	1.00	1.00	1.00
18-petri-net-alignment	1.00	1.00	1.00	1.00	1.00	2.23
18-settlers	1.00	1.18	1.00	1.41	1.00	1.38
18-snake	1.00	1.25	1.00	1.44	1.00	2.13
18-spider	1.00	1.19	1.00	1.35	1.01	1.40
18-termes	1.01	1.17	1.03	1.20	1.18	1.22

Table 4: Normalized cost for IPC domains. N/A indicates no problem was solved.

E Results on Pure Type-based Exploration in the Focal

In this section, we analyze the performance of a search that is based purely on our type-based exploration in the focal. Unlike Type-WA*, we do not alternate with WA*, and instead perform all expansions using focal exploration.

E.1 Results for $w = 3$

Table 5 shows the coverage for h^{MS}, h^{LM}, and h^{LC} with $w = 3$. We can see that pure type-based focal exploration performs well and for h^{MS} and h^{LM} it even outperforms WA* in terms of coverage. Still, Type-WA* outperforms both WA* and pure type-based focal exploration.

		h^{MS}			h^{LM}			h^{LC}		
Domain	#	WA*	T	TWA*	WA*	T	TWA*	WA*	T	TWA*
14-barman	14	3	6.0	6.0	3	6.0	6.0	0	3.0	3.0
14-cavediving	20	7	7.0	7.0	7	8.0	7.8	3	3.0	3.0
14-childsnack	20	0	4.4	4.4	0	4.0	3.8	0	5.0	5.0
14-citycar	20	15	17.8	18.2	13	19.0	19.6	0	0.0	0.0
14-floortile	20	6	2.0	5.2	2	1.4	2.0	12	11.4	14.6
14-ged	20	20	20.0	20.0	15	17.8	17.4	19	19.8	19.8
14-hiking	20	20	20.0	20.0	18	17.4	19.6	13	13.8	14.2
14-maintenance	5	5	5.0	5.0	5	5.0	5.0	5	5.0	5.0
14-openstacks	20	3	1.0	2.0	3	1.0	1.0	3	1.0	2.0
14-parking	20	13	16.0	12.4	9	5.2	9.0	16	9.8	15.6
14-tetris	17	7	7.0	7.0	12	17.0	17.0	8	8.2	8.4
14-tidybot	20	7	15.0	15.8	17	20.0	20.0	16	12.6	15.0
14-transport	20	7	10.0	13.8	9	7.4	8.0	8	3.6	8.4
14-visitall	20	6	9.0	9.0	20	14.0	20.0	13	13.0	12.8
18-agricola	20	0	17.0	20.0	0	14.6	20.0	0	1.0	2.6
18-caldera	20	10	16.0	16.6	16	20.0	20.0	0	0.0	0.0
18-data-network	20	11	17.0	18.0	13	17.0	18.0	13	16.0	17.6
18-nurikabe	20	11	13.6	14.0	16	17.6	17.8	0	0.0	0.0
18-organic-synthesis	20	7	7.0	7.0	7	7.0	7.0	7	7.0	7.0
18-petri-net-alignment	20	4	2.0	3.0	2	0.0	2.0	12	3.0	12.0
18-settlers	20	8	11.0	11.8	13	13.0	13.0	0	0.0	0.0
18-snake	20	11	14.0	14.8	14	15.0	15.8	7	8.8	9.2
18-spider	20	11	12.0	12.0	19	15.2	17.2	12	10.4	12.4
18-termes	20	15	12.0	12.0	12	12.2	14.2	8	12.0	12.0
Total	456	207	261.8	**275.0**	245	274.8	**301.2**	175	167.4	**199.6**

Table 5: Number of solved instances in IPC domain by WA*, type-based focal exploration (T), and Type-WA* (TWA*).

E.2 Results for different w

Table 6 shows the coverage for h^{MS} with different values of w. Again, we find that pure type-based focal exploration performs well even outperforms WA* in terms of coverage. Still, Type-WA* outperforms both WA* and pure type-based focal exploration.

		$w = 2$			$w = 3$			$w = 10$		
Domain	#	WA*	T	TWA*	WA*	T	TWA*	WA*	T	TWA*
14-barman	14	1	3.0	3.0	3	6.0	6.0	6	8.2	8.2
14-cavediving	20	7	7.0	7.0	7	7.0	7.0	7	7.0	7.0
14-childsnack	20	0	2.0	2.0	0	4.4	4.4	5	4.4	4.8
14-citycar	20	15	16.6	17.4	15	17.8	18.2	16	18.2	18.2
14-floortile	20	9	2.4	8.0	6	2.0	5.2	2	0.2	2.0
14-ged	20	19	20.0	20.0	20	20.0	20.0	20	20.0	20.0
14-hiking	20	16	18.0	19.0	20	20.0	20.0	20	20.0	20.0
14-maintenance	5	5	5.0	5.0	5	5.0	5.0	5	5.0	5.0
14-openstacks	20	3	1.0	2.0	3	1.0	2.0	3	0.8	1.0
14-parking	20	8	16.0	16.0	13	16.0	12.4	16	16.0	16.0
14-tetris	17	7	7.0	7.0	7	7.0	7.0	7	7.0	7.0
14-tidybot	20	7	12.4	12.4	7	15.0	15.8	7	17.6	17.6
14-transport	20	7	8.0	10.0	7	10.0	13.8	7	14.8	14.8
14-visitall	20	5	6.6	7.8	6	9.0	9.0	9	12.0	12.0
18-agricola	20	0	14.0	18.2	0	17.0	20.0	1	20.0	20.0
18-caldera	20	10	13.0	15.6	10	16.0	16.6	10	17.2	16.0
18-data-network	20	12	15.0	16.0	11	17.0	18.0	13	19.6	19.8
18-nurikabe	20	11	12.0	12.0	11	13.6	14.0	12	15.0	15.0
18-organic-synthesis	20	7	7.0	7.0	7	7.0	7.0	7	7.0	7.0
18-petri-net-alignment	20	4	2.0	3.0	4	2.0	3.0	4	1.2	11.6
18-settlers	20	8	8.8	9.8	8	11.0	11.8	11	12.2	11.2
18-snake	20	11	13.8	14.0	11	14.0	14.8	11	18.2	19.8
18-spider	20	11	12.0	12.0	11	12.0	12.0	12	12.0	12.0
18-termes	20	13	12.0	12.0	15	12.0	12.0	16	9.6	11.8
Total	456	196	234.6	**256.2**	207	261.8	**275.0**	227	283.2	**297.8**

Table 6: Number of solved instances in IPC domain by WA*, type-based focal exploration (T), and Type-WA* (TWA*).

E.3 Results on Solution Cost

Table 7 shows the average normalized cost for WA* and Type-WA* with h^{MS} for $w \in \{2, 3, 10\}$. Since the normalized cost is averaged only over solved problems, we also report the number of solved problems. For $w = 2$ and $w = 3$, we observe minor differences in solution cost between Type-WA* and pure type-based focal exploration. For $w = 10$, pure type-based focal exploration find solutions that, on average, have higher cost. Note that the normalized cost is computed based on the lowest cost solution found by any of the configurations and, as we have additional configurations in this experiment, the results for WA* and Type-WA* may have minor differences from the results in Table 2.

	$w = 2$			$w = 3$			$w = 10$		
	WA*	T	TWA*	WA*	T	TWA*	WA*	T	TWA*
Cost	1.01	1.11	1.12	1.03	1.23	1.25	1.10	1.76	1.69
# Solved	196	234.6	256.2	207	261.8	275.0	227	283.2	297.8

Table 7: Normalized cost and # of solved instances on IPC domains.