THE UNIVERSITY OF MELBOURNE

Approximate Novelty Search

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Motivation

Need for planners that can **exploit higher range of novelty values with linear time complexity**.

Key Issue

- Checking that a state has novelty k requires in the worst case keeping track in memory of all previously seen exponential number of tuples, along with enumerating as many tuples for each state.
- This results in impractical runtimes to compute novelty values greater than 2.

We address this issue by proposing new methods to obtain polynomial approximations of novelty and to control the growth of the memory footprint of BFWS algorithms.

Background

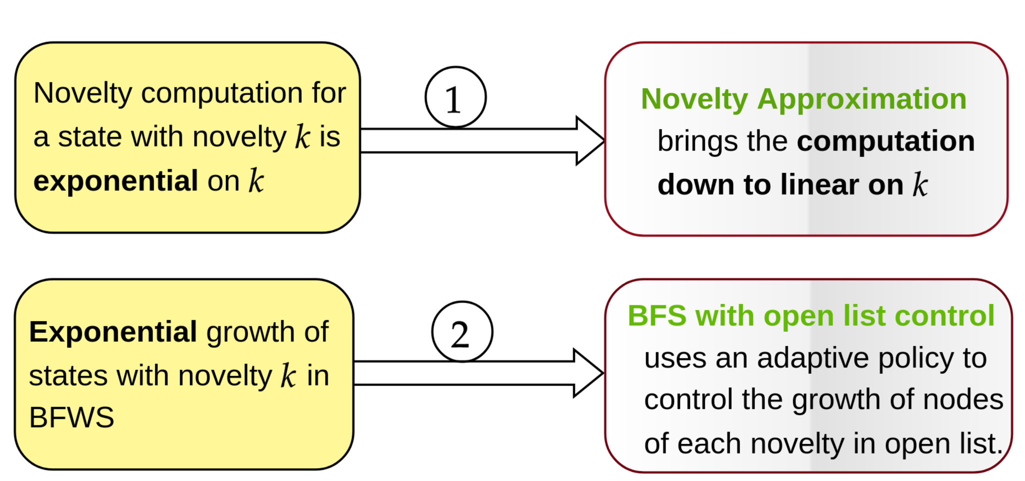
Best-First Width Search (BFWS)

- BFWS [1] is a family of BFS algorithms where the evaluation function for a node n, $f(n)$ is defined as a tuple of functions $f(n) = (w, h_1, \ldots, h_m)$.
- $w : S \to \mathcal{W}$ is the function measuring novelty, and $H = \{h_1, \ldots, h_m\}$ is a set of suitably chosen functions.

Novelty

The *novelty* $w(s) = w_{\langle H \rangle}(s)$ of a newly generated state s given a set of partition functions H over states $s \in S$ is k, iff (1) exists a tuple(conjunction of atoms) $t \subseteq F$ of *minimum* size k, s.t. $s \models t$, (2) $\forall s' \in \mathcal{P}(s, H)$, $s' \not\models t$.

Core contributions



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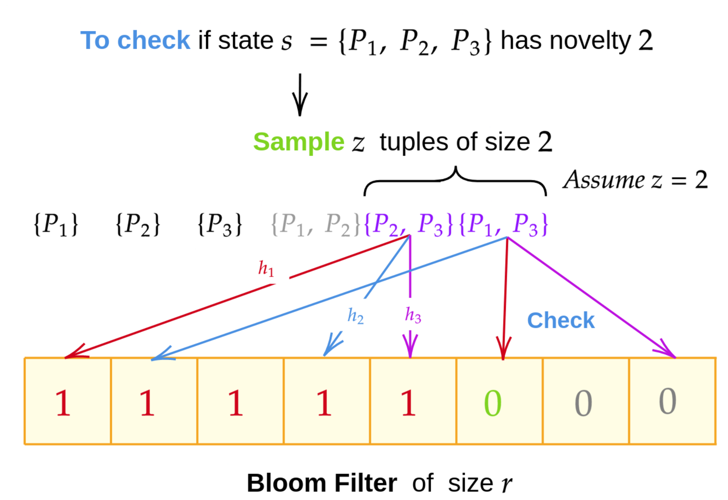
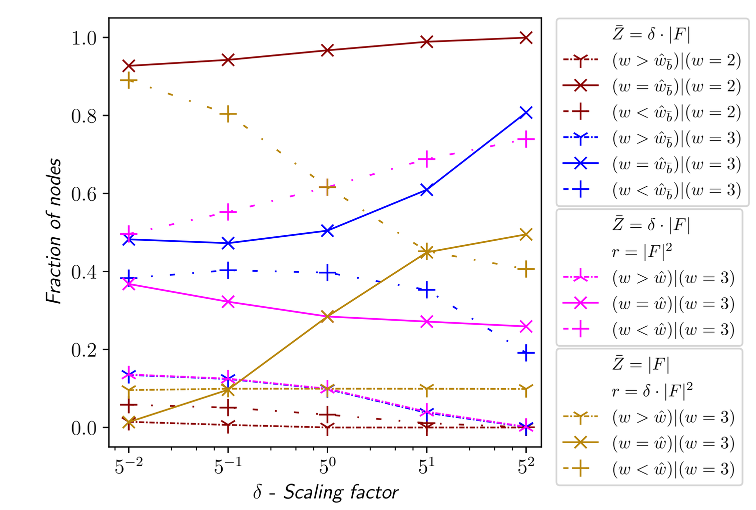
Research Output

Sequential polynomial planner which beats the state-of-the-art.

Novelty Approximation



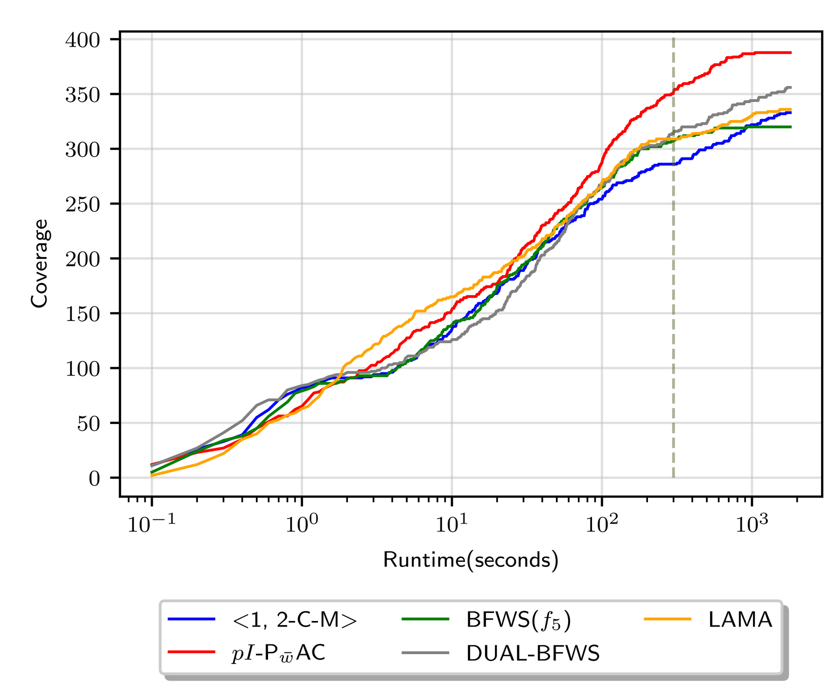
(a) *Steps* involved in computation of novelty of a state



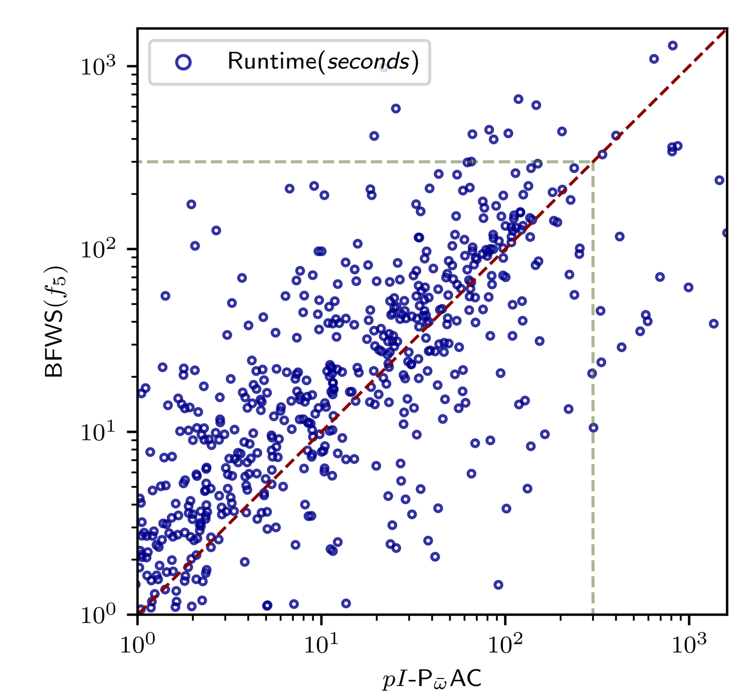
(b) Variation in the rate of *accurate* ($w = \hat{w}$), *lower* ($w > \hat{w}$) and *higher* ($w < \hat{w}$) approximation of novelty w over different sizes of sample($\bar{Z}$) and Bloom Filter(r).

Analytically derived bounds on the probability of approximate novelty value being higher or lower than actual value are in agreement with the *variation* presented in the figure.

Performance against state-of-the-art planners



(c) *Coverage* over *time(seconds)* on IPC 2014 and 2018 satisficing benchmarks.



(d) Pairwise comparison of runtime, over All IPC satisficing benchmarks, between BFWS(f_5) and pI-P$_{\bar{\omega}}$AC.

Best First Search with Open List Control

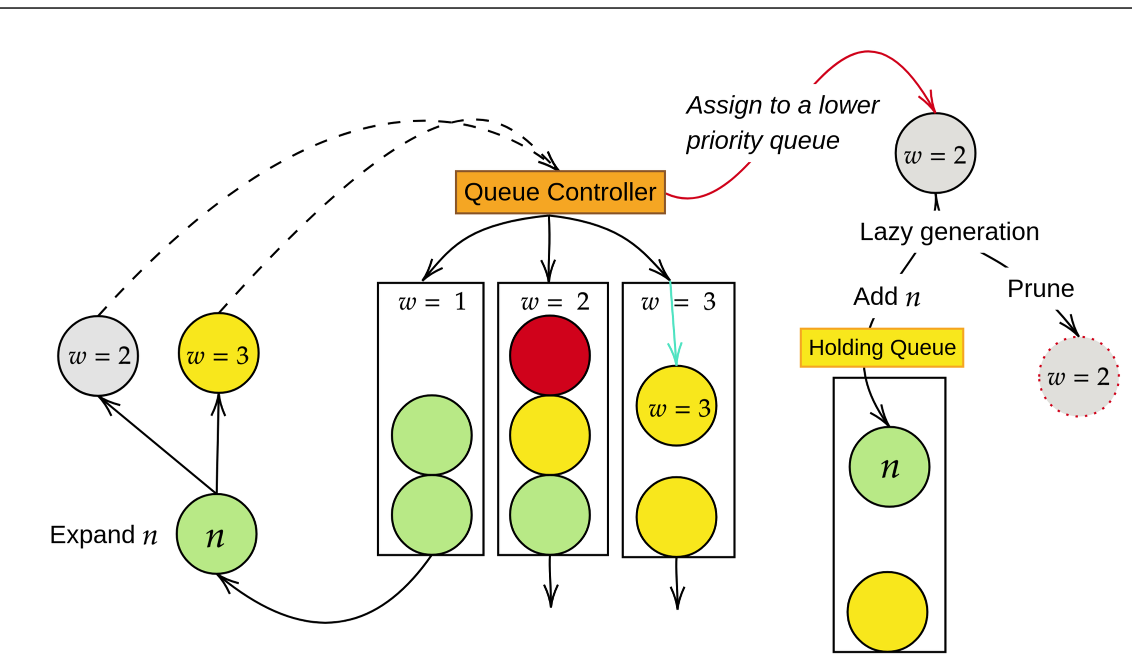


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Figure 1. The *working* of Best first search with Open List Control

Best First Search with Open List Control

We derive the policy from the analytical solution to an infinite-horizon MDP, where its cost function controls the representation of different novelty categories in the open list.

$$\mu^{\omega}(x_k) = \begin{cases} 1 - \left(\frac{n_e}{n_v(\omega)}\right)^{\frac{1}{2}}, & \text{if } n_e/n_v(\omega) < 1 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Results on IPC benchmarks

- We use every benchmark in the IPC *satisficing* track to evaluate the performance of new planners that use $\hat{w}$.
- We **compare our new planners against notable *polynomial* planners**: BFWS(f_5) with novelty pruning and $\langle 1, 2$-C-M$\rangle$, a sequential polynomial planner [2], **as well as two state-of-the-art planners DUAL-BFWS [1] and LAMA-*first* [3].**

IPC	LAMA	DUAL-BFWS	BFWS-f_5	k-BFWS	$\langle 1, 2$-C-M$\rangle$	P$_3$AC	p-P$_3$A	pI-P$_{\bar{\omega}}$AC	pI-$\mathcal{L}_{\bar{\omega}}$AC
Total (1691)	1456	1496	1436	1414	1456	1502±4.9	1462±8.0	1524±2.5	1516±5.0

Table 1. Coverage over all satisficing benchmarks from IPCs: The *mean coverage* is shown along with the *standard deviation* for the planners that use sampling.

Takeaways

- The proposed methods of novelty approximation and open list control in *BFWS* not only have positive impact on coverage but also on the overall time and space complexity of the search, resulting in new state-of-the-art planners over satisficing benchmarks from every IPC since 1998 and more significantly the last 2 IPCs (2014 and 2018).
- These results strongly suggest that probabilistically complete search algorithms are a promising research direction in classical planning.
- We hope this work brings about the insights to develop the next generation of classical planners, that scale up better as the intractability of the benchmarks ramps up and tackle the inherent limitations of BFS.

References

[1] Nir Lipovetzky and Hector Geffner. Best-first width search: Exploration and exploitation in classical planning. In *Proc. of the AAAI Conference on Artificial Intelligence*, 2017.

[2] Nir Lipovetzky and Hector Geffner. A polynomial planning algorithm that beats lama and ff. In *International Conference on Automated Planning and Scheduling*, 2017.

[3] Silvia Richter and Matthias Westphal. The lama planner: Guiding cost-based anytime planning with landmarks. *Journal of Artificial Intelligence Research*, 39:127–177, 2010.

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