Novelty Heuristics, Multi-Queue Search, and Portfolios for Numeric Planning

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The problem we are solving.

- Numeric Planning (satisficing)
- States now exhibit numeric variables
- Conditions are arithmetic expressions of numeric vars

Contributions

- Bring together some classical search techniques
  - novelty heuristics [1,6]
  - multi-queue search [2]
  - portfolios [3]
- New simple heuristic $h^{md} = h^{Manhatten\_Distance}$
  - goal count + sum of numeric goal errors
- Empirical evaluation on IPC 2023 Numeric Track
  - new satisficing numeric planner baseline

Numeric Novelty Heuristics

two steps to construct numeric novelty heuristics:

1. define a *novelty feature*

$$f : S^{<\mathbb{N}} \times S \to (\mathbb{R} \cup \{\perp\})^N$$

"vector representation of a state, based on previously seen states"

2. given a novelty feature and base heuristic, define a *novelty heuristic*

$$n_f^h : S^{<\mathbb{N}} \times S \to \mathbb{R}$$

"map states to scalar values, based on previously seen states"

1. Novelty Features

- **Assignment (A)**

assign value for numeric variable

assign truth value for propositional variable

- **Boundary (B)** [4] (Figure also from same reference)

online boundaries based on min/max of numeric values

more numeric than **(A)**

less refined than **(A)**

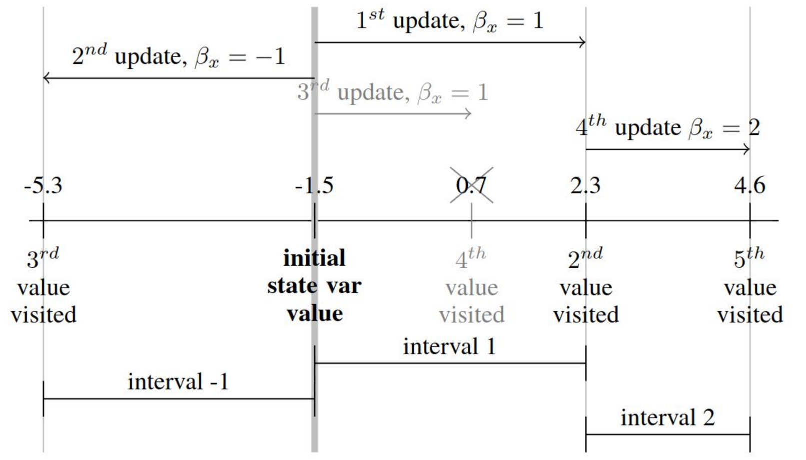

Figure 1: Example of the boundary extension encoding (BEE) on a single state variable. The value 0.7 has $\mathcal{B} = \{\beta_x = 1\}$ because it does not contribute to extend the boundaries of the visited values of the state variable (it falls in the 1^{st} visited interval). $w(s)$ will be greater than 1 and s will be pruned if no other boundary is extended.

2. Novelty Heuristics

Let J denote a variable subset

- **Partition Novelty (^{k}PN)** [5]

J in state s is novel iff its feature is new in previously seen states t with $h(s) = h(t)$

- **Quantified Both (^{k}QB)** [6] (We extend to general case k>1)

J in state s is novel iff $h(s) < h(t)$ for all other states t with the same feature for J

then we count novel variable subsets but also prioritise states with small novel subsets

$\varphi(J, s)$ = novel subset
$\psi(J, s)$ = bad subset

$$\begin{cases} \sum_{n=1}^{1} \binom{N}{n} - \sum_{J \in \left\{ {N \atop 1} \right\}} \varphi(J, s), & \text{if } \exists J \in \left\{ {N \atop 1} \right\}, \varphi(J, s) \\ \vdots & \\ \sum_{n=1}^{k} \binom{N}{n} - \sum_{J \in \left\{ {N \atop k} \right\}} \varphi(J, s), & \text{if } \exists J \in \left\{ {N \atop k} \right\}, \varphi(J, s) \\ \sum_{n=1}^{k} \binom{N}{n} + \sum_{J \in \left\{ {N \atop k} \right\}} \psi(J, s), & \text{otherwise,} \end{cases}$$

Combining Heuristics

1. Multi-Queue/Alternating Search

   one search queue for each heuristic

2. (Static) Portfolios

   try each configuration with n_heuristics^{-1} of the time limit

Experiments

- IPC 2023 Numeric Track, 20 domains x 20 problems
- 5 minute timeout

  8 GB memory

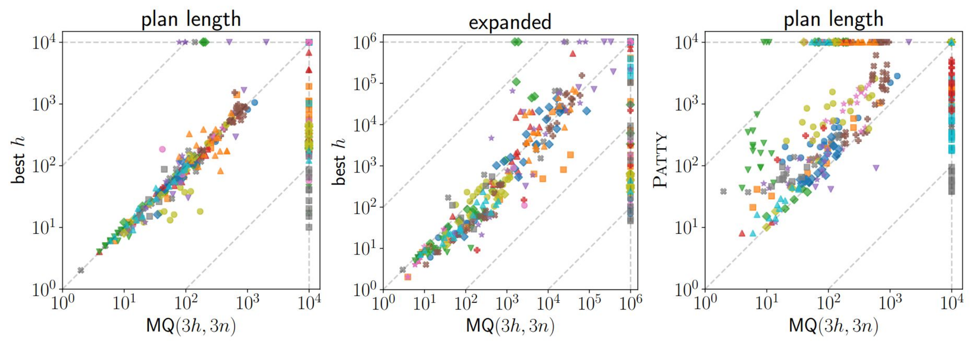

Figure 2: Left and center: best h, the best SQ GBFS planner for each problem, vs $\mathrm{M}(3h\|3n)$ on sequential plan length and number of expanded nodes. Right: PATTY vs $\mathrm{M}(3h\|3n)$ on sequential plan length. Points on the top left triangle favour $\mathrm{M}(3h\|3n)$ and points on the bottom right favour best h and PATTY on the respective plots.

- Portfolios (P) > Multi-Queue (M) search
- Search > SMT for plan quality

	SQ GBFS						MQ GBFS			PF GBFS			SMT	
domain	h^{md}	h^{add}	h^{mrp}_{+hj}	$h^{md}_{\langle B,QB\rangle}$	$h^{add}_{\langle B,QB\rangle}$	$h^{mrp}_{\langle B,QB\rangle}$ +hj	M($3h$)	M($3n$)	M($3h\|3n$)	P($3h$)	P($3n$)	P($3h\|3n$)	PATTY	best
block-grouping	15	16	19	15	15	19	16	12	15	18	16	17	**20**	20
counters	13	13	**20**	10	10	**20**	14	9	11	**20**	19	**20**	**20**	20
delivery	17	14	10	14	11	10	**19**	10	17	18	12	16	5	19
drone	**20**	11	17	5	15	17	16	18	17	19	16	19	4	20
expedition	3	2	-	3	6	-	3	5	**8**	3	6	6	3	8
ext-plant-watering	12	12	**20**	1	19	**20**	17	**20**	**20**	**20**	**20**	**20**	6	20
farmland	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	20
fo-counters	9	7	-	15	12	-	9	14	14	8	14	10	**20**	20
fo-farmland	**20**	5	13	**20**	**20**	14	**20**	**20**	**20**	**20**	**20**	**20**	**20**	20
fo-sailing	-	4	-	-	1	-	3	-	-	3	1	4	**20**	20
hydropower	3	2	-	18	**20**	-	3	**20**	**20**	2	**20**	**20**	**20**	20
markettrader	17	4	-	**20**	**20**	-	15	**20**	**20**	17	**20**	19	-	20
mprime	7	16	16	12	18	16	**19**	18	17	17	18	18	14	19
pathwaysmetric	-	2	12	-	2	13	3	2	3	12	13	12	**20**	20
rover	10	4	7	12	5	7	13	12	**16**	11	12	12	**16**	16
sailing	-	18	**20**	-	17	**20**	**20**	19	**20**	**20**	**20**	**20**	**20**	20
settlersnumeric	-	2	3	-	-	4	4	-	2	4	3	**5**	-	5
sugar	1	9	16	-	8	18	12	9	9	18	18	19	**20**	20
tpp	**20**	3	4	5	4	4	17	4	7	**20**	4	**20**	3	20
zenotravel	13	19	**20**	15	13	**20**	18	12	18	**20**	**20**	18	11	20
sum	200	183	217	185	236	222	261	244	274	290	292	**315**	262	367

Coverage of various configurations of single queue (S), multi-queue (M), and portfolio (P) GBFS, and the PATTY solver on the NT-IPC domains. The rightmost column records the highest coverage for each domain. The top scores for each row except the rightmost column are indicated by the cell colour intensity with the top score being highlighted in bold.

[1] Nir Lipovetzky, Hector Geffner. *Best-First Width Search: Exploration and Exploitation in Classical Planning.* AAAI 2017
[2] Gabriele Röger, Malte Helmert. *The More, the Merrier: Combining Heuristic Estimators for Satisficing Planning.* ICAPS 2010
[3] Malte Helmert, Gabriele Röger, Erez Karpas. *Fast Downward Stone Soup: A Baseline for Building Planner Portfolios.* ICAPS 2011 Workshop on Planning and Learning.
[4] Florent Teichteil-Königsbuch, Miquel Ramírez, Nir Lipovetzky. *Boundary Extension Features for Width-Based Planning with Simulators on Continuous-State Domains.* IJCAI 2020
[5] Nir Lipovetzky, Hector Geffner. *Width and Serialization of Classical Planning Problems*. ECAI 2012
[6] Michael Katz, Nir Lipovetzky, Dany Moshkovich, Alexander Tuisov. *Adapting Novelty to Classical Planning as Heuristic Search.* ICAPS 2017