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

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SoCS

What are we doing: numeric planning (PDDL 2.1)

States (resp. actions) now have numeric variables (resp. conditions and effects)

- Undecidable with decidable fragments
- Useful for modelling:
  - capacity constraints
  - resource management
  - Euclidean maps
  - games and puzzles

```
(:action pickup
  :parameters (?r - robot ?o - item)
  :precondition (and ((clear ?o)
                      (<= (+ (weight ?o) (load ?r)) (limit ?r))))
  :effect (and ((not (clear ?o))
                (holding ?r ?o)
                (increase (load ?r) (weight ?o)))))
```

Contributions

Ctrl+C, Ctrl+V classical search techniques to numeric planning

1. unifying novelty heuristics for numeric planning
2. multi-queue search
3. portfolios

Big coverage tables and empirical results on IPC 2023 Numeric Track

1. Numeric Novelty Heuristics

Two steps for defining a novelty heuristic

1. define a *novelty feature*

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

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

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

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

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

1.1. Example Novelty Features

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

Two examples:

- Assignment (A)
- Boundary (B)

1.1.1. Novelty Feature: Assignment Feature

Assignment (A)

- assign truth value of propositional variables
- assign numeric value of numeric variables

1.1.2. Novelty Feature: Boundary Feature

Boundary[1] (B)

- incrementally build intervals from min/max of numeric vals
- assign numeric value to interval

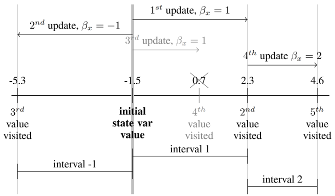


Image from [1]

[1] Florent Teichteil-Königsbuch, Miquel Ramírez, and Nir Lipovetzky. "Boundary Extension Features for Width-Based Planning with Simulators on Continuous-State Domains". In: *IJCAI*. 2020.

1.2. Example Novelty Heuristics

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

Two examples:

- Partition Novelty (PN)
- Quantified Both (QB)

Some notation:

- fix $k \in \mathbb{N} \setminus \{0\}$
- let J denote indices of a feature, $|J| \leq k$
- $[J]^s$ the values of feature at J in s

1.2.1. Novelty Heuristic: Novelty Partition

Partition Novelty[1] (^{k}PN)

- J in s is novel iff $[J]^s$ is new in previous states t with $h(s) = h(t)$
- heuristic = minimum size of novel Js

[1] Nir Lipovetzky and Hector Geffner. "Width and Serialization of Classical Planning Problems". In: *ECAI*. 2012.

1.2.2. Novelty Heuristic: Quantified Both

Quantified Both[1] (^{k}QB).

- new: *we generalise QB for arbitrary k*
- J in s is novel iff $h(s) < h(t)$ for previous states t with $[J]^s = [J]^t$
- heuristic = count novel variable subsets while
  - prioritising states with small novel subsets
  - tiebreaking on 'bad' subsets

[1] Michael Katz et al. "Adapting Novelty to Classical Planning as Heuristic Search". In: *ICAPS*. 2017.

2. Combining Heuristics

1. Multi-Queue Search/Alternation Search[1] (M)
   - one search queue for each heuristic
2. (Static) Portfolios[2] (P)
   - try each configuration with $\frac{1}{|\text{heuristics}|}$ of the time limit

[1] Gabriele Röger and Malte Helmert. "The More, the Merrier: Combining Heuristic Estimators for Satisficing Planning". In: *ICAPS*. 2010.

[2] Malte Helmert, Gabriele Röger, and Erez Karpas. "Fast Downward Stone Soup: A Baseline for Building Planner Portfolios". In: *ICAPS 2011 Workshop on Planning and Learning*. 2011.

3. Experiments

- IPC 2023 Numeric Track, 20 domains $\times$ 20 problems
- 5 minute timeout, 8GB memory

- Try (numeric h^{add})[1] with {novelty features} $\times$ {novelty heuristics}
- $k = 2$

Numeric Heuristics							Novelty Heuristics			
h^{gc}	h^{md}	h^{aibr}	h^{add}	h^{radd}	h^{mrp}	$h^{\text{mrp}}+\text{hj}$	$h^{\text{add}}_{\langle A,PN\rangle}$	$h^{\text{add}}_{\langle B,PN\rangle}$	$h^{\text{add}}_{\langle A,QB\rangle}$	$h^{\text{add}}_{\langle B,QB\rangle}$
117	200	119	183	171	176	217	178	181	215	**236**

Abbreviations:

- A: Assignment novelty feature
- B: Boundary novelty feature
- PN: Partition Novelty novelty heuristic
- QB: Quantified Both novelty heuristic

*Results may differ on specific domains

1. h^{add} best standalone heuristic
2. QB $>$ PN
3. B $>$ A (slightly)

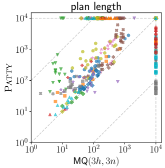
[1] Enrico Scala, Patrik Haslum, and Sylvie Thiébaux. "Heuristics for Numeric Planning via Subgoaling". In: *IJCAI*. 2016.

3.2. Experiments: Combining Heuristics

Define

- $3h = [h^{\text{md}}, h^{\text{add}}, h^{\text{mrp}}+\text{hj}]$ (list of top 3 performing heuristics)
- $3n = 3h$ with B nov. features and QB nov. heuristics
- $\text{M}(\cdot)$ = multi-queue of input heuristics
- $\text{P}(\cdot)$ = static portfolio of input heuristics
- PATTY = state-of-the-art SMT numeric planner on IPC 2023 Numeric benchmarks[1]

M GBFS			P GBFS			SMT
$\text{M}(3h)$	$\text{M}(3n)$	$\text{M}(3h\|\|3n)$	$\text{P}(3h)$	$\text{P}(3n)$	$\text{P}(3h\|\|3n)$	PATTY
261	244	274	290	292	**315**	262



*Results may differ on specific domains

1. Portfolios > Multi-Queue

2. Search > SMT; in both *coverage* and *plan length*

[1] Matteo Cardellini, Enrico Giunchiglia, and Marco Maratea. "Symbolic Numeric Planning with Patterns". In: *AAAI*. 2024.

Future for Numeric Planning

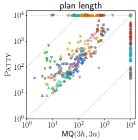
- more benchmarks ($\sim$ 90% solved by us or SMT)
- more applications (due to better scaling)
- plenty to do for optimal numeric planning
- learning

Porting classic search techniques to numeric planning

1. Unify definition of novelty heuristics
   - new: extending QB to arbitrary k
2. New simple heuristic h^{md} (not in this talk)
3. Experiments with mostly nice conclusions
   - QB novelty heuristic works best
   - Portfolios generally outperforms multi-queue/alternation search
   - Search generally outperforms constraint-based solving

Numeric Heuristics							Novelty Heuristics			
h^{gc}	h^{md}	h^{aibr}	h^{add}	h^{radd}	h^{mrp}	h^{mrp}+hj	$h^{\mathrm{add}}_{\langle A,PN\rangle}$	$h^{\mathrm{add}}_{\langle B,PN\rangle}$	$h^{\mathrm{add}}_{\langle A,QB\rangle}$	$h^{\mathrm{add}}_{\langle B,QB\rangle}$
117	200	119	183	171	176	217	178	181	215	**236**

M GBFS			P GBFS			SMT
M(3h)	M(3n)	M(3h‖3n)	P(3h)	P(3n)	P(3h‖3n)	PATTY
261	244	274	290	292	**315**	262



Abbreviations:
- A: Assignment novelty feature
- B: Boundary novelty feature
- PN: Partition Novelty novelty heuristic
- QB: Quantified Both novelty heuristic
- M: Multi-Queue/Alternation Search for combining heuristics
- P: Portfolios for combining heuristics

Thanks! Questions? code at `https://github.com/DillonZChen/numeric-planner-2024.git`