Search-Guidance Mechanisms for Numeric Planning through Subgoaling Relaxation

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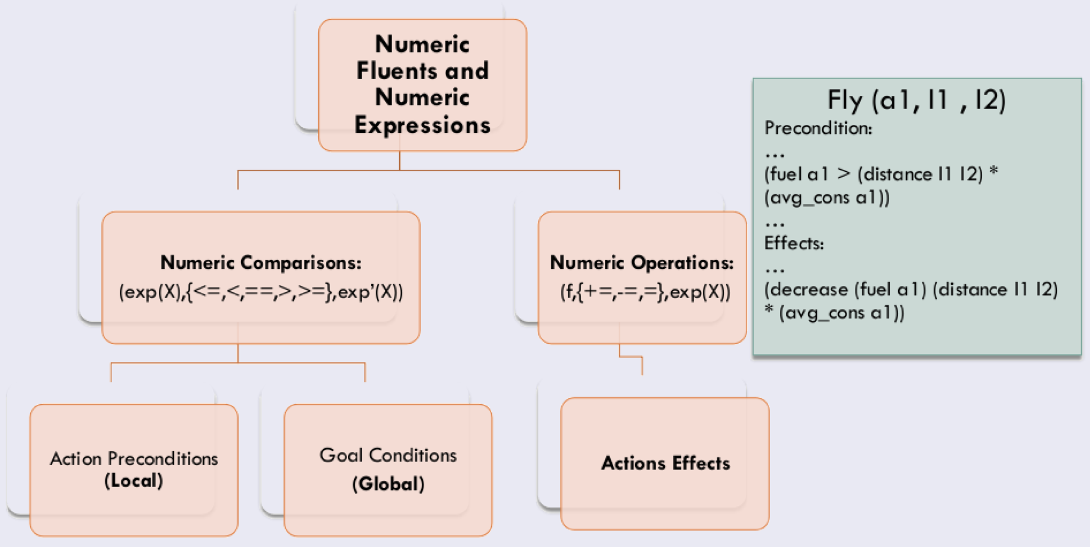
Abstract

The subgoaling-based relaxation is grounded on the identification of regression-based necessary conditions for the satisfaction of sets of numeric subgoals. So far, it has been used to define novel heuristics to provide guidance in problems exhibiting a pronounced numeric structure. This work investigates how to further exploit this relaxation to better integrate it within the search. It does so introducing the notion of a of multi-repetition relaxed plan (MRP). A MRP enables a novel relaxed plan based heuristic, subgoaling based helpful actions, and the extraction of what we call up-to-jumping actions. Results show consistent improvement over the majority of benchmarks under evaluation

The Problem : Numeric Planning

Numeric Planning challenging because needs to integrate reasoning over propositional and numeric variables. Numeric variables complicate a lot the reasoning



State of The Art, Issues and Research Question

Previous work and Issues

- Solving numeric planning through heuristic search: devise heuristics from relaxed version of the problem. Known schemata:
- Interval-Based Relaxation (IBR) (Metric-FF, Colin, LPG,...). Generality ok, but can be very coarse relaxation for easier yet significant problems
- Subgoaling-Based Relaxation and heuristics h^{max}, h^{add} for numeric planning

Focus and Research Questions

- Subgoaling principle to design novel heuristics and search-guidance in Simple Numeric Planning Problems
- How to better exploit and integrate subgoaling relaxation into search?
- Results:
  - **Multi-Repetition Plan Heuristic**
  - **More informed Helpful Actions**
  - **Up-To-Jumping Actions**

Background: Subgoaling-Based Relaxation for Simple Numeric Planning

Definition (Simple Numeric Planning)

Let Π be a numeric planning problem. A numeric condition $\xi \trianglerighteq k$ is *simple* iff ξ is a linear arithmetic expression and all variables in ξ are affected only by action effects that increase/decrease them by constant values. Problem Π is simple iff all numeric preconditions of its actions and goals are simple.

Definition (m-times-regressor)

Let $c \doteq (\sum_{x \in X} w_{x,c} x) + w_{n,c} \trianglerighteq 0$ (with $\trianglerighteq \in \{\leq, <, >, \geq\}$, $w_{x,c}$ and $w_{n,c} \in \mathbb{Q}$) be a simple numeric condition. The m-times regressor $c^{r(a,m)}$ of c through action a is:

$$c^{r(a,m)} \doteq \sum_{x \in X} w_{x,c}(k_{x,a} m + x) + w_{n,c} \trianglerighteq 0$$

where $m \in \mathbb{N}$, and $k_{x,a}$ is the constant additive effect of a on x (i.e., $\langle x, +=, k_{x,a} \rangle \in \text{eff}(a)$).

Definition (Possible Achiever)

We say that action a is a *possible achiever* of c in a state s if there exists an $m \in \mathbb{N}$ such that $s \models c^{r(a,m)}$.

$$\hat{h}^{add}_{hbd}(s,c) \doteq \begin{cases} 0 & \text{if } s \models c \\ \min\limits_{a \in ach(c)} \left(\lambda(a) + \hat{h}^{add}_{hbd}(s, \text{pre}(a))\right) & \text{if } c \text{ is PC} \\ \min\limits_{\substack{a \in A, \hat{m} \in \mathbb{Q}^{\geq 0} \\ s \models c^{r(a,\hat{m})}}} \left(\hat{m}\lambda(a) + \hat{h}^{add}_{hbd}(s, \text{pre}(a))\right) & \text{if } c \text{ is SC} \\ \sum\limits_{c' \subset c : |c'|=1} \hat{h}^{add}_{hbd}(s,c') & \text{if } |c| > 1 \end{cases}$$

Key Ideas:

- Distinguish propositional from numeric terms
- Approximate numeric achievers through a multi-step regression
- Solve recurrence equation interleaving propositional and numeric regression throughout best achievers
- Approximate counting with continuous relaxation (enables looking for optimal solutions using actions in isolation)

Relaxed Plan Computation and the h^{MRP}_{max} Heuristic

Definition (From the estimate to an actual plan)

$$\pi(s,c) \doteq \begin{cases} \{\} & \text{if } s \models c \\ \{(a, m(s,a,c))\} \cup \pi(s, \text{pre}(a)) & \text{if } |c| = 1 \\ \quad \text{with } a = best(s,c) & \\ \bigcup_{c' \in c} \pi(s,c') & \text{if } |c| > 1 \end{cases}$$

$$best(s,c) \doteq \operatorname*{arg\,min}_{\substack{a \in A, \hat{m} \in \mathbb{Q}^{\geq 0} \\ s \models c^{r(a,\hat{m})}}} \left(\hat{m}\lambda(a) + \hat{h}^{add}_{hbd}(s, \text{pre}(a))\right)$$

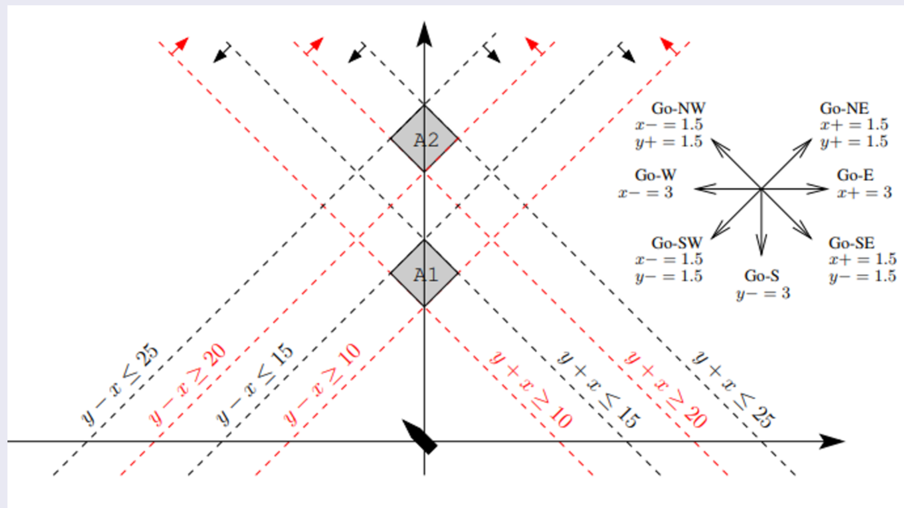
- Similar to Keyder and Geffner's formulation, but with account for actions needed multiple times
- It can be proved that the procedure terminates in a finite number of steps. Indeed, best achievers are calculated in polynomial time, the backward procedure is a greedy process that only appends the already established achiever to the working relaxed plan.

Definition (The h^{MRP}_{max} heuristic)

$$h^{MRP}_{max}(s,G) \doteq \sum_{a \in \{a^* | (a^*, m^*) \in \pi\}} \lambda(a) \cdot \max_{(a,m') \in \pi(s,G)} \{m'\}$$

- Need to account for the fact that the same actions can occur multiple times, with different molteplicity

Sailing Example



- Goal: reach area A1 and A2, wind from the north
- $\hat{h}^{add}_{hbd+} = 22$. Sums up all the actions required to get both $y - x \geq 10 \land y - x \geq 20 \land y + x \geq 10 \land y + x \geq 20$. Obviously overcounting!
- $h^{MRP}_{max} = 16$. A possible plan that can be generated (assuming tie-breaking is deterministic in choosing achievers). It manages to capture some information sharing

Helpful Actions and Up-To-Jumping Actions

Definition (Subgoaling Helpful Actions)

An action a is said to be helpful in a state s w.r.t. relaxed plan π iff: i) a is applicable in s and ii) there exists a $g \in \bigcup_{(a',m') \in \pi} \text{pre}(a') \cup G$ where $s \not\models g$, and $g \in \text{eff}(a)^+$ or $\exists \hat{m} \in \mathbb{Q}^{\geq 0} \cdot s \models g^{r(a,\hat{m})}$ (acc. Def. **??**). We denote with $H(s)$ the set of all helpful actions in s

Definition (Up-to-jumping Action, Syntax and Semantics)

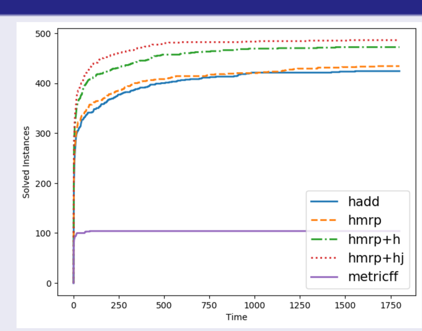
An *up-to-jumping action* is a pair (a,m) where $a \in A$ and $m \in \mathbb{N}$. An up-to-jumping action (a,m) is executable in a state s if the precondition of a are satisfied in s (as a regular action); the state resulting form executing (a,m) in s is obtained by repeating the execution of a until either it is executed m times or a state where the preconditions of a are not satisfied is generated by $m' < m$ executions of a.

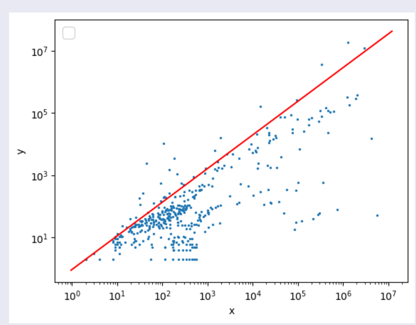
$$J(s) = \{(a,m) \,|\, (a,m) \in \pi, m > 1, \forall (a,m') \in \pi \; m \leq m'\}$$

Experimental Results

Domain	$\hat{h}^{add}_{hbd}$	h^{MRP}_{max}	$h^{MRP}_{max}+H$	$h^{MRP}_{max}+HJ$	h^{mff}
Heavily-Numeric					
Counters (11)	6	6	9	**11**	1
Counters-Inv (11)	6	6	8	**10**	1
Counters-Rnd (33)	26	26	**33**	32	8
Gardening (51)	51	51	51	51	0
Farmland (50)	50	50	50	50	0
Grouping (192)	159	156	168	**178**	17
Sailing (40)	37	**40**	**40**	**40**	3
From IPCs					
Depots (23)	10	16	18	**19**	3
Rover (20)	11	11	**12**	**12**	10
Satellite (20)	7	10	**14**	**14**	7
Settlers (20)	4	4	6	6	1
ZenoTravel (23)	22	**23**	**23**	**23**	22
Depots (C)(23)	15	18	**19**	**19**	2
Satellite (C)(22)	4	4	4	4	7
ZenoTravel (C)(23)	16	13	**17**	**17**	**22**
Total	424	434	472	**486**	104

Table: Coverage of systems across all domains. In parenthesis, the number of instances for a given domain. +H stands for using helpful actions pruning. +HJ up-to-jumping actions, too





- (Above) Number of problem solved as timeout increases
- (Below) Number of expanded nodes between $\hat{h}^{add}_{hbd+}$ and $h^{MRP}_{max} + HJ$

Future Work

- Explore use of up-to-jumping actions with optimal planning
- Investigate the use of redundant constraints in relaxed-plan heuristics
- Verify compatiblity with non-simple numeric planning problems