# Effect-Abstraction Based Relaxation for Linear Numeric Planning

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# Outline

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- Numeric Effect-Abstraction
- Effect-Abstraction Subgoaling Relaxation
    - Theoretical Result
    - A Novel Heuristic — $h_{abs}^{add}$
- Evaluation
- Conclusion and Future Work

# Motivation and Problem Statement

- Solve planning problems by heuristic search
- Heuristics by Relaxation
  - A relaxation problem is **an easier problem** (usually could be solved in polynomial time), which can provide useful information on how to solve the master problem.
  - Relaxations are at the basis of state-of-art planners.
  - Tighter relaxation usually translates to more informative heuristics.

# Motivation and Problem Statement

- **Comparison of Existing Relaxations**

| | (Additive) Interval-based [1, 2, 3] | | Subgoaling [4, 5] |
|---|---|---|---|
| Problem Spectrum | General (e.g. non-linear effects) | $>$ | Simple (i.e. constant additive effects) |
| Tightness | Looser | $<$ | Tighter |

Table 1: Comparison between existing relaxations for numeric planning problems.

- **Research Questions:** can we find a relaxation that
  - handles a fragment that sits between general and simple planning;
  - tighter than Interval-based relaxation.

# Motivation and Problem Statement

- **Linear Numeric Planning Problem**

  Subclass of PDDL 2.1 level 2

  - Numeric state variables
  - Preconditions, effects, goals involving numbers and *linear* arithmetic expressions.

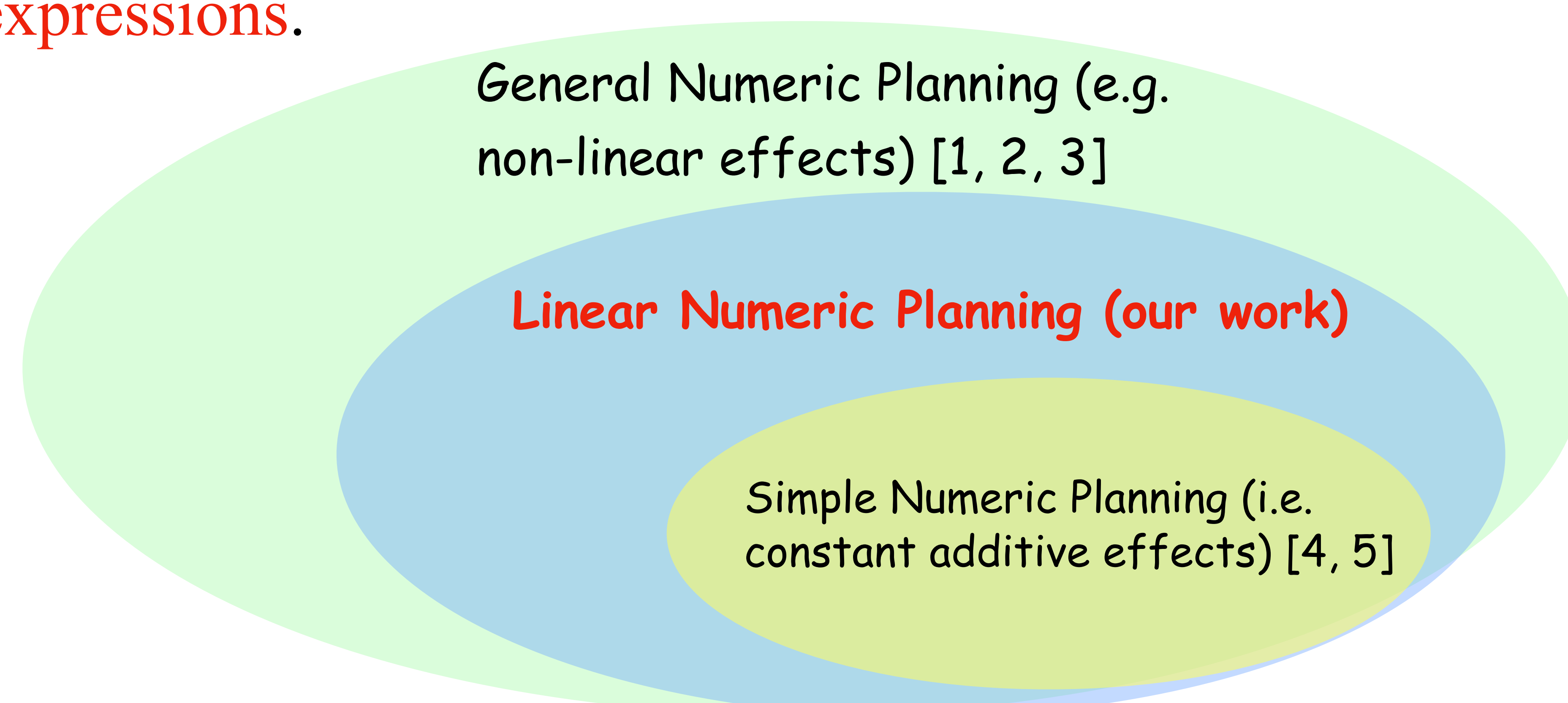



Figure 1. Relations among different numeric planning problems.

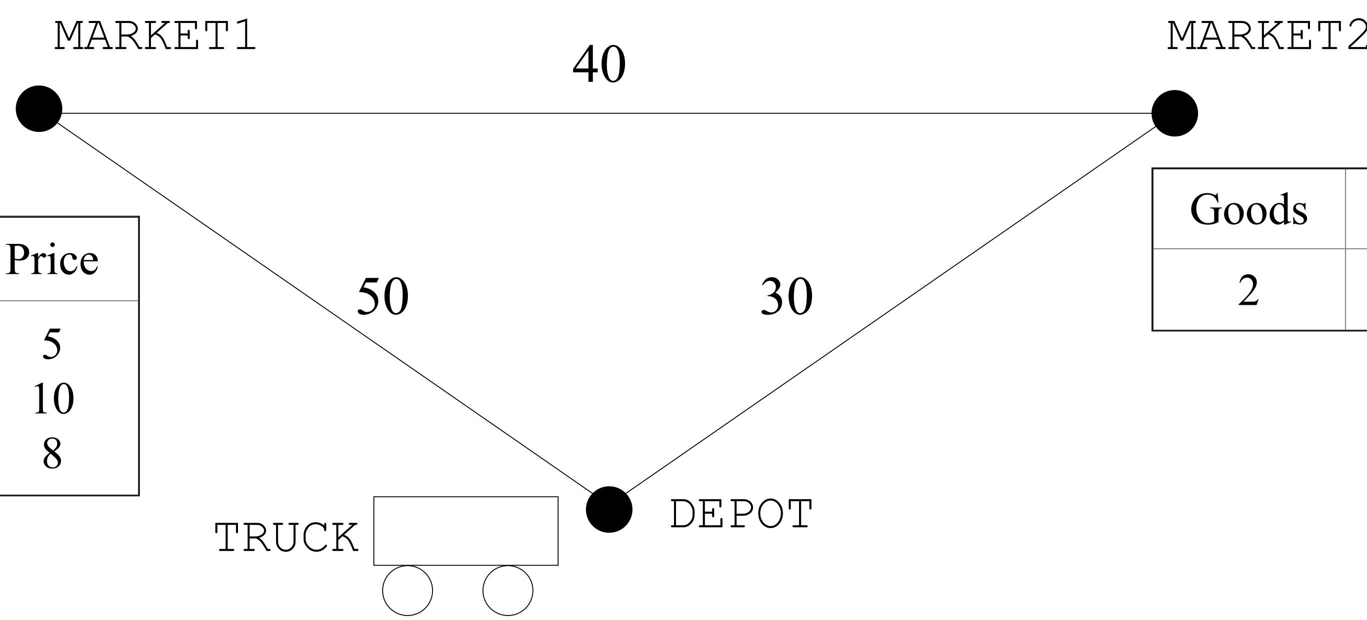
# Motivation and Problem Statement

- **Example**: TPP-Metric problem

  The #goods to purchase depends on #request - #bought, which is linear.

```
:effect (and (decrease (on-sale ?g ?m) (- (request ?g) (bought ?g)))
```

| Goods | Amount | Price |
|---|---|---|
| 1 | 14 | 5 |
| 2 | 100 | 10 |
| 3 | 20 | 8 |




| Goods | Amount | Price |
|---|---|---|
| 2 | 200 | 2 |

Figure 2. TPP-metric problem.

# Motivation and Problem Statement

- **Contribution**

1. Propose **a general effect-abstraction scheme** to compile linear numeric planning problems into simple (conditional) numeric planning problems;
2. Propose **effect-abstraction subgoaling relaxation**, proved to be tighter than Additive Interval-based Relaxation (AIBR);
3. Prove a **safeness condition** for effect-abstraction subgoaling relaxation;
4. A new and competitive **heuristic** $h_{abs}^{add}$

# Numeric Effect-Abstraction

- **Observation**:

Linear numeric effect is a compact representation of (potentially) infinite number of *conditional effects*.

E.g. consider the effect

```
:effect (decrease (on-sale ?g ?m) (- (request ?g) (bought ?g))
```

Only if `#request-#bought` evaluates to some amount *n*, `#on-sale` could be decreased by the same amount *n*.

Namely, one conditional effect could be formulated as:

```
:effect (when (=(-(request ?g) (bought ?g) n))
                        (decrease (on-sale ?g ?m) n)
```

# Numeric Effect-Abstraction

- Abstraction by coarsening numeric effects
- Numeric Effect-Abstraction

**Master Problem (Linear)**

$$\Pi$$

$$\Big\downarrow \ \textbf{Numeric Effect Abstraction } \Gamma_{\langle D,T \rangle}(\cdot)$$

**Effect-abstraction Problem (Simple)**

$$\Gamma_{\langle D,T \rangle}(\Pi)$$

Figure 2. Numeric Effect-Abstraction scheme.

# Numeric Effect-Abstraction

- **Numeric Effect Abstraction:** $\Gamma_{\langle D,T \rangle}(\Pi)$

***D(e)*** **- Decomposition**

- Partition possibly reachable values of *rhs(e)* into disjoint intervals;
- The boundaries of such intervals induce additional conditions when linear numeric effect is activated.

***T(e)*** **- Tagging**

- A tagging function *T(e)* : $D(e) \to \mathbb{Q}$ maps every interval $l \in D(e)$ to a specific value $T(e)(l)$ in $D(e)$ .
- Use *T(e)* as a coarsened representative of the effect when the right-hand side evaluates to a member in *D(e)*.

# Numeric Effect-Abstraction

- **Numeric Effect Abstraction**

  **Compiling into conditional effects**

$$\{\langle rhs(e) \in l, \langle lhs(e), op(e), T(e)(l)\rangle\rangle : l \in D(e)\}$$

- **Example**

```
#on-sale -= #request - #bought

:effect (and
          (when (and (> (-(request ?g) (bought ?g) 0))
                     (<=(-(request ?g) (bought ?g) 4)))
                (decrease (on-sale ?g ?m) 2))
          (when (and (> (-(request ?g) (bought ?g) 4))
                     (<=(-(request ?g) (bought ?g) 10)))
                (decrease (on-sale ?g ?m) 6))
                               . . .
          )
```

# Effect-Abstraction Subgoaling Relaxation

- **Effect-Abstraction Subgoaling Relaxation**

**Master Problem (Linear)**

$$\Pi$$

**Numeric Effect Abstraction** $\Gamma_{\langle D,T \rangle}(\cdot)$

**Effect-abstraction Problem (Simple)**

$$\Gamma_{\langle D,T \rangle}(\Pi)$$

**Subgoaling Relaxation**

$$\Gamma_{\langle D,T \rangle}(\Pi)^1$$

Figure 3. Effect-Abstraction Subgoaling Relaxation

# Effect-Abstraction Subgoaling Relaxation - Theoretical Result

- **Safeness Condition**

  ***Theorem***

  $\Gamma_{\langle D,T\rangle}(\Pi)^1$ has no solution implies $\Pi$ has no solution if for every effect:

$$\forall l \in D(e) : \bar{l} \cdot \underline{l} > 0$$

- **Tightness**

  Under the Theorem, for any choice of *T,* effect-abstraction subgoaling relaxation is tighter than AIBR.

# Effect-Abstraction Subgoaling Relaxation - A Novel Heuristic $h^{add}_{abs}$

- **AIBR-based Decomposition (ABD)**

1. Use additive interval-based relaxation (AIBR) to (over-)approximate reachable values for the right-hand side.
2. Track the progression of intervals as the decomposition.

- **Midpoint Tag Function (MTF)**

$$MTF(I) = \begin{cases} \underline{I} + \epsilon & \text{if } \overline{I} = \infty \\ \overline{I} - \epsilon & \text{if } \underline{I} = -\infty \\ \frac{\underline{I} + \overline{I}}{2} & \text{otherwise} \end{cases}$$

- $h^{add}_{abs}$

Apply $h^{add}_{hbd+}$ on the abstraction problem.

$$h^{add}_{abs}(\Pi, s_0) = h^{add}_{hbd+}(\Gamma_{\langle ABD, MTF \rangle}(\Pi), s_0)$$

# Evaluation

- **Domains**

  1. IPC domain TPP-Metric;

  2. Extensions of simple numeric planning domains (Counters, Sailing, Farmland).

| | Coverage | | | CPU-Time (s) | | | Plan Length | | | Exp. Nodes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ |
| FO-COUNT(20) | **8** | **8** | **8** | 39.4 | **8.9** | 56.3 | **17.5** | 20.4 | 21.9 | 24991.1 | 5807.8 | **2239.6** |
| FO-COUNT-INV(20) | **8** | 6 | 6 | **1.0** | 67.7 | 13.0 | **22.0** | 24.0 | 26.5 | **804.0** | 70880.8 | 970.3 |
| FO-COUNT-RND(60) | **31** | 24 | 21 | **9.6** | 33.0 | 123.1 | **19.7** | 22.3 | 19.9 | **5755.3** | 25085.0 | 9582.7 |
| FO-SAILING(20) | **17** | 4 | 5 | **1.0** | 344.0 | 160.6 | 91.0 | **74.0** | 126.3 | **92.0** | 997881.7 | 36323.0 |
| FO-FARMLAND(50) | **50** | **50** | **50** | **0.7** | 2.0 | 64.8 | 58.1 | 26.8 | **26.3** | **60.4** | 638.8 | 172.4 |
| TPP-METRIC(40) | **20** | 8 | 10 | **2.9** | 123.3 | 107.8 | **20.5** | 20.8 | 23.2 | **29.6** | 91546.9 | 144.0 |
| Total | **134** | 100 | 100 | | | | | | | | | |

Table 2: Comparison between existing heuristics for linear numeric planning problems. Time, plan length and expansions are averages over instances solved with the first three heuristics. Bold is for best performer. Timeout is 1800 seconds.

# Conclusion and Future Work

**Conclusion**

1. **Numeric effect-abstraction**: a general scheme to apply relaxations/heuristics for simple numeric planning with more complex numeric effects;
2. Proved **safeness condition** in combination with numeric subgoaling relaxation/heuristics;
3. A new and competitive **heuristic** $h_{abs}^{add}$

**Future Work**

Expand to other relaxations/heuristics and effects beyond linear.

# Reference

[1] Hoffmann, J. (2003). The Metric-FF Planning System: Translating``Ignoring Delete Lists''to Numeric State Variables. *Journal of artificial intelligence research*, *20*, 291-341.

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[3] Aldinger, J., Mattmüller, R., & Göbelbecker, M. (2015, September). Complexity of interval relaxed numeric planning. In *Joint German/Austrian Conference on Artificial Intelligence (Künstliche Intelligenz)* (pp. 19-31). Springer, Cham.

[4] Scala, E., Haslum, P., & Thiébaux, S. (2016, July). Heuristics for Numeric Planning via Subgoaling. In *IJCAI* (pp. 3228-3234).

[5] Piacentini, C., Castro, M., Cire, A., & Beck, J. C. (2018). Linear and integer programming-based heuristics for costoptimal numeric planning. AAAI.

# Appendix

We also compared $h^{add}_{abs}$ with Metric-FF.

1. Much better than FF heuristics with GBFS;
2. Even solved more problem instances than Metric-FF full system.

Note that ENHSP with $h^{add}_{abs}$ and GBFS is complete, while Metric-FF with helpful action pruning, hill-climbing search is not.

| | Coverage | | | CPU-Time (s) | | | Plan Length | | | Exp. Nodes | | | Coverage | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{add}_{abs}$ | $h^{aibr}$ | $\hat{h}^{add}_{hbd+}$ | $h^{FF}_{\text{LNF}}$ | M-FF |
| FO-COUNT(20) | **8** | **8** | **8** | 39.4 | **8.9** | 56.3 | **17.5** | 20.4 | 21.9 | 24991.1 | 5807.8 | **2239.6** | 1 | 8 |
| FO-COUNT-INV(20) | **8** | 6 | 6 | **1.0** | 67.7 | 13.0 | **22.0** | 24.0 | 26.5 | **804.0** | 70880.8 | 970.3 | 1 | 7 |
| FO-COUNT-RND(60) | **31** | 24 | 21 | **9.6** | 33.0 | 123.1 | **19.7** | 22.3 | 19.9 | **5755.3** | 25085.0 | 9582.7 | 0 | 23 |
| FO-SAILING(20) | **17** | 4 | 5 | **1.0** | 344.0 | 160.6 | 91.0 | **74.0** | 126.3 | **92.0** | 997881.7 | 36323.0 | 0 | 11 |
| FO-FARMLAND(50) | **50** | **50** | **50** | **0.7** | 2.0 | 64.8 | 58.1 | 26.8 | **26.3** | **60.4** | 638.8 | 172.4 | 0 | 38 |
| TPP-METRIC(40) | **20** | 8 | 10 | **2.9** | 123.3 | 107.8 | **20.5** | 20.8 | 23.2 | **29.6** | 91546.9 | 144.0 | 6 | 40 |
| Total | **134** | 100 | 100 | | | | | | | | | | 8 | 127 |

Table 3: Comparison result including Metric-FF (present in paper).