Translations from Discretised PDDL+ to Numeric Planning

Francesco Percassi[1], Enrico Scala[2], Mauro Vallati[1]

[1] School of Computing and Engineering, University of Huddersfield, UK

[2] Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia, Italy

ICAPS 2021

Abstract

Hybrid PDDL+ models are amongst the most advanced models of systems and the resulting problems are notoriously difficult for planning engines to cope with. An additional limiting factor for the exploitation of PDDL+ approaches in real-world applications is the restricted number of domain-independent planning engines that can reason upon those models. With the aim of deepening the understanding of PDDL+ models, in this work we study a novel mapping between a time discretisation of PDDL+ and numeric planning as for PDDL2.1 (level 2). The proposed mapping not only clarifies the relationship between these two formalisms, but also enables the use of a wider pool of engines, thus fostering the use of hybrid planning in real-world applications. Our experimental analysis shows the usefulness of the proposed translation, and demonstrates the potential of the approach for improving the solvability of complex PDDL+ instances.

PDDL+ problem

A PDDL+ problem is a tuple $\Pi = \langle\langle F, X, I, G, A\rangle, E, P\rangle$ where:

- $\langle F, X, I, G, A\rangle$ is PDDL2.1 task; an action $a \in A$ is a pair $\langle p, e\rangle$ where p is a formula and e is a set of conditional effects of the form $c \triangleright e$ where (i) c is a formula and (ii) e is a set of Boolean ($\langle f := \{\bot, \top\}\rangle$) or numeric ($\langle\{asgn, inc, dec\}, x, \xi\rangle$ where ξ is an expression over X and rational numbers) assignments.
- E and P are the sets of **events** and **processes**, respectively; a process is a pair $\langle p, e'\rangle$ where p is a formula and e' is a set of numeric continuous effects expressed as pairs $\langle x, \xi\rangle$ with the meaning that ξ represents the time-derivative of x, with $x \in X$; an event has a similar structure to an action.

*Intuitively, a PDDL+ problem consists of finding a number of actions along with a potentially infinite timeline, whilst conforming to a number of processes and events that may change the state of the world in a **continuous** or an **instantaneous** manner as time goes by.*

Research questions Is there a way to discretise a PDDL+ problem into a numeric problem? In what relation are these two formalisms? Can we benefit from it?

EXP translation

Let $\delta \in \mathbb{Q}$ be the **discretisation step** and let $\Delta(\xi, \delta)$ be the discretised ξ according to δ. Let $\mathcal{P}^+(P)$ the set of non-empty subsets of P. We call $\mathcal{C} \in \mathcal{P}^+(P)$ **context**. For an event-free PDDL+ problem Π, the exponential translation generates a PDDL2.1 problem $\Pi_{\text{EXP}} = \langle F, X, I, G, A \cup \{SIM\}, c\rangle$, discretised in $t = \delta$:

$$SIM = \langle \top, \bigcup_{\mathcal{C} \in \mathcal{P}^+(P)} \{cpre(\mathcal{C}) \triangleright ceff(\mathcal{C})\rangle$$

$$cpre(\mathcal{C}) = \bigwedge_{\rho \in P \setminus \mathcal{C}} \neg pre(\rho) \wedge \bigwedge_{\rho \in P \cap \mathcal{C}} pre(\rho), \;\; ceff(\mathcal{C}) = \bigcup_{x \in X} \{\langle inc, x, \sum_{\substack{\langle x', \xi\rangle \in eff(\rho) \\ x' = x,\ \rho \in \mathcal{C}}} \Delta(\xi, \delta)\rangle\}$$

POLY translation

For an event-free PDDL+ problem Π, the polynomial translation generates a PDDL2.1 problem $\Pi_{\text{POLY}} = \langle F \cup D \cup p\}, X \cup X^{cp}, I, G \wedge \neg p, A_c \cup A_P \cup \{start, end\}, c\rangle$ such that (p stands for *pause* and d stands for *done*):

$$X^{cp} = \{x^{copy} \mid x \in X\}, D = \bigcup_{\substack{ne \in eff(\rho) \\ \rho \in P}} \{d_{ne}\}, \;\; A_c = \{\langle pre(a) \wedge \neg p, eff(a)\rangle \mid a \in A\}$$

$$start = \langle \neg p, \{p\} \cup \bigcup_{x \in X} \{\langle ass, x^{copy}, x\rangle\}\rangle, \;\; end = \langle \bigwedge_{d \in D} d \wedge p, \{\neg p\} \cup \bigcup_{d \in D} \{\neg d\}\rangle$$

$$A_P = \bigcup_{\substack{ne:\langle x, \xi\rangle \in eff(\rho) \\ \rho \in P}} \{\langle p \wedge \neg d_{ne}, \{\sigma(pre(\rho), X^{cp}) \triangleright \{\langle inc, x, \Delta(\delta, \sigma(\xi, X^{cp}))\rangle\}\} \cup \{d_{ne}\}\rangle\}$$

Events Handling

The novel $SIMEV = \langle sim\text{-}ev, \mathcal{W}_{trig} \cup \mathcal{W}_{fired} \cup \mathcal{W}_{satu} \cup \mathcal{W}_{\bot}\rangle$ action handle the **events simulation triggering** also for **cascading** events provided that they give rise to **finite** and **acyclic** sequences of triggering. Every action and every simulation of the passage of time makes *sim-ev* true, thus forcing the execution of a sequence of *SIMEV* (at least once).

$$\mathcal{W}_{trig} = \bigcup_{\substack{c \triangleright e \in eff(\varepsilon) \\ \varepsilon \in E}} \{pre(\varepsilon) \wedge c \triangleright e\}, \;\; \mathcal{W}_{fired} = \bigcup_{\varepsilon \in E} \{pre(\varepsilon) \triangleright fired_\varepsilon\}$$

$$\mathcal{W}_{satu} = \Big\{ \bigwedge_{\varepsilon \in E} (\neg pre(\varepsilon) \vee fired_\varepsilon) \triangleright \{\neg sim\text{-}ev\} \cup \bigcup_{\varepsilon \in E} \{\neg fired_\varepsilon\} \Big\}$$

$$\mathcal{W}_{\bot} = \Big\{ \Big(\bigvee_{\substack{\varepsilon, \varepsilon' \in E: \\ \varepsilon \neq \varepsilon' \wedge \\ mutex(\varepsilon, \varepsilon')}} pre(\varepsilon) \wedge pre(\varepsilon') \vee \bigvee_{\varepsilon \in E} pre(\varepsilon) \wedge fired_\varepsilon \triangleright \{\bot\} \Big\}$$

Examples of Translation

EXP Let $\Pi = \langle F, X, I, G, A, \emptyset, P\rangle$ be a PDDL+ problem without events encompassing one Boolean variable, i.e., $F = \{f_1\}$, four numeric variables, i.e., $X = \{x_1, x_2, x_3, x_4\}$ and two processes $P = \{\rho_1, \rho_2\}$ such that:

$$\rho_1 = \langle x_1 > 0, \{\langle x_2, x_3\rangle\}\rangle, \;\; \rho_2 = \langle f_1, \{\langle x_2, x_4\rangle\}\rangle$$

According to the continuous semantic, e.g., ρ_1 affects x_2 according to $\frac{dx_2}{dt} = x_3$ when $x_1 > 0$ holds. The PDDL2.1 problem obtained using EXP discretised in $t = \delta$ is $\Pi_{\text{EXP}} = \langle F, X, I, G, A \cup \{SIM\}, c\rangle$. The novel action *SIM* features a conditional effect for each element in $\mathcal{P}^+(P) = \{\{\rho_1\}, \{\rho_2\}, \{\rho_1, \rho_2\}\}$, i.e., $SIM = \langle \top, \mathcal{W}_{\{\rho_1\}}, \mathcal{W}_{\{\rho_2\}}, \mathcal{W}_{\{\rho_1, \rho_2\}}\rangle$, where:

$$\mathcal{W}_{\{\rho_1\}} = (x_1 > 0) \wedge \neg f_1 \triangleright \{\langle inc, x_2, x_3 \cdot \delta\rangle\}$$
$$\mathcal{W}_{\{\rho_2\}} = \neg(x_1 > 0) \wedge f_1 \triangleright \{\langle inc, x_2, x_4 \cdot \delta\rangle\}$$
$$\mathcal{W}_{\{\rho_1, \rho_2\}} = (x_1 > 0) \wedge f_1 \triangleright \{\langle inc, x_2, (x_3 + x_4) \cdot \delta\rangle\}$$

POLY Let $ne_1 = \langle x_2, x_3\rangle$ and $ne_2 = \langle x_2, x_4\rangle$ be the numeric continuous effects of ρ_1 and ρ_2, respectively. The PDDL2.1 problem obtained using POLY discretised in $t = \delta$ is $\Pi_{\text{POLY}} = \langle F \cup \{d_1, d_2\} \cup \{p\}, X \cup \{x_1^{copy}, x_2^{copy}, x_3^{copy}, x_4^{copy}\}, I, G \wedge \neg p, A_c \cup \{SIM\text{-}1, SIM\text{-}2\} \cup \{start, end\}, c\rangle$ such that:

$$start = \langle \neg p, \{\langle ass, x_1^{copy}, x_1\rangle, \langle ass, x_2^{copy}, x_2\rangle, \langle ass, x_3^{copy}, x_3\rangle, \langle ass, x_4^{copy}, x_4\rangle, p\}\rangle$$
$$SIM\text{-}1 = \langle p \wedge \neg d_{ne_1}, \{(x_1^{copy} > 0) \triangleright \{\langle inc, x_2, x_3^{copy} \cdot \delta\rangle\}, d_{ne_1}\}\rangle$$
$$SIM\text{-}2 = \langle p \wedge \neg d_{ne_2}, \{f_1 \triangleright \{\langle inc, x_2, x_4^{copy} \cdot \delta\rangle\}, d_{ne_2}\}\rangle$$
$$end = \langle p \wedge d_{ne_1} \wedge d_{ne_2}, \{\neg p, \neg d_{ne_1}, \neg d_{ne_2}\}\rangle$$

Properties

Lemma Let Π be a PDDL+ problem, and let Π_{EXP} (Π_{POLY}) be the PDDL2.1 problem obtained by using the EXP (POLY) translation discretised in $t = \delta$. Π admits a solution under δ discretisation iff so does Π'.

Theorem 1 Let Π be a PDDL+ problem, and let $\Pi_{\text{EXP}}^{events}$ ($\Pi_{\text{POLY}}^{events}$) be the PDDL2.1 problem obtained by using the EXP (POLY) translation. Π admits a solution under δ discretisation iff so does $\Pi_{\text{EXP}}^{events}$ ($\Pi_{\text{POLY}}^{events}$).

Theorem 2 Let Π be a PDDL+ problem, and let $\Pi_{\text{POLY}}^{events}$ and $\Pi_{\text{EXP}}^{events}$ be the PDDL2.1 problems obtained by using the POLY and EXP translations, respectively. Translations POLY and EXP preserve plan size **polynomially** in the sense of Nebel.

Experimental Results

Domain	METRIC-FF		DINO	ENHSP	SMTPLAN
	POLY	EXP			
Rover (20)	**20**	**20**	**20**	5	19
Linear-Car (10)	**10**	**10**	**10**	**10**	**10**
Linear-Generator (10)	**10**	3	**10**	**10**	**10**
UTC (10)	**7**	0	0	**7**	0
Baxter (20)	**19**	0	7	17	8
Overtaking-Car (20)	18	**19**	0	**19**	0
TOTAL	**84**	52	47	68	47

Selected Bibliography

- Fox, M.; and Long, D. 2003. PDDL2.1: An extension to PDDL for expressing temporal planning domains. *J. Artif. Intell. Res.* 20: 61–124.
- Fox, M.; and Long, D. 2006. Modelling Mixed Discrete-Continuous Domains for Planning. *J. Artif. Intell. Res.* 27:235–297.
- Nebel, B. 2000. On the Compilability and Expressive Powerof Propositional Planning Formalisms. *J. Artif. Intell. Res.* 12: 271–315.
- Shin, J.; and Davis, E. 2005. Processes and continuous change in a SAT-based planner. *Artificial Intelligence* 166:194–253.