https://github.com/whitemech/Plan4Past

Planning for Temporally Extended Goals in Pure-Past Linear Temporal Logic

Best Student Paper Award

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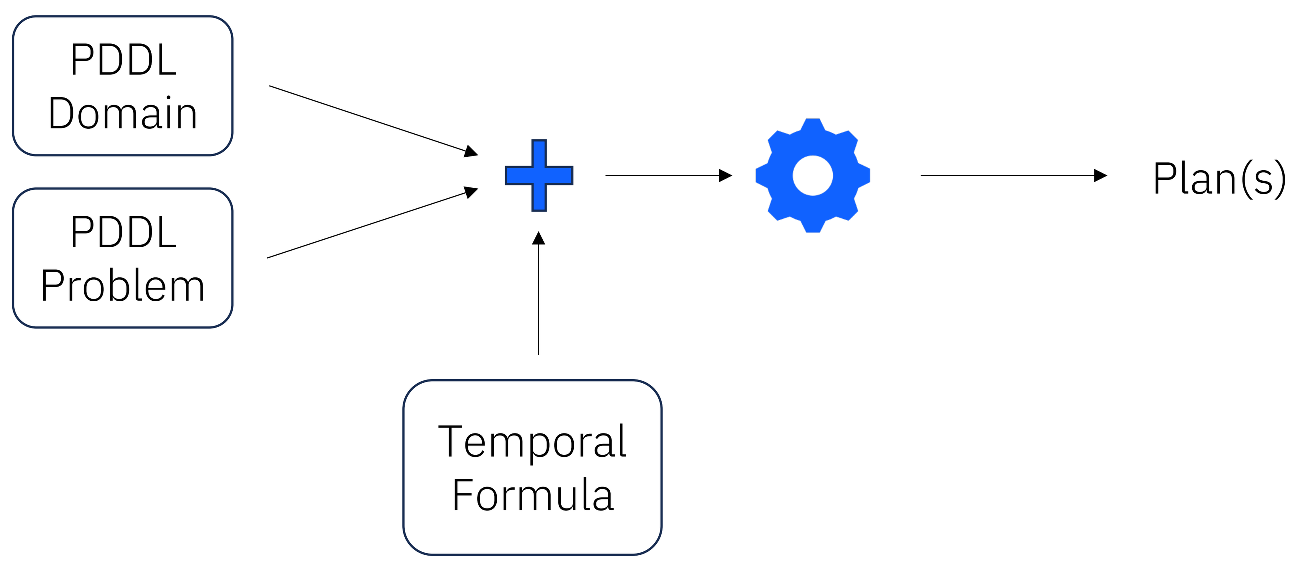
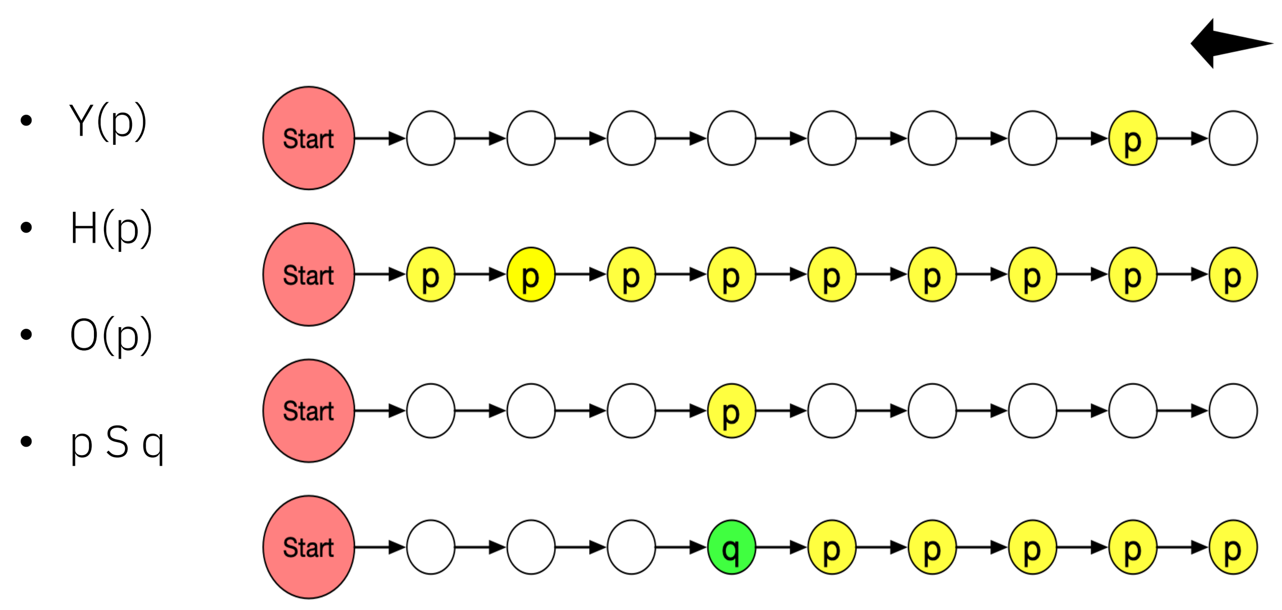
Context

Restrict the way the planner achieves the goal



Pure-Past Linear-time Temporal Logic

- Talks about properties of the world with past temporal operators only: (Y)esterday, (H)istorically, (O)nce, (S)ince
- PPLTL looks at the trace backward, and evaluates formulas on the last instant of the trace (i.e., the current instant)



Useful PPLTL Patterns

DECLARE Template	Equivalent PPLTL Formula	Equivalent LTL_f Formula
init(a)	$\mathsf{O}(a \wedge \neg\mathsf{Y}(true))$	a
existence(a)	$\mathsf{O}(a)$	$\mathsf{F}(a)$
absence(a)	$\neg\mathsf{O}(a)$	$\neg\mathsf{F}(a)$
absence2(a)	$\mathsf{H}(a \rightarrow \mathsf{WYH}(\neg a))$	$\neg(\mathsf{F}a \wedge \mathsf{XF}(a))$
choice(a, b)	$\mathsf{O}(a) \vee \mathsf{O}(b)$	$\mathsf{F}(a) \vee \mathsf{F}(b)$
exclusive-choice(a, b)	$(\mathsf{O}(a) \vee \mathsf{O}(b)) \wedge \neg(\mathsf{O}(a) \wedge \mathsf{O}(b))$	$(\mathsf{F}(a) \vee \mathsf{F}(b)) \wedge \neg(\mathsf{F}(a) \wedge \mathsf{F}(b))$
co-existence(a, b)	$\mathsf{H}(\neg a) \leftrightarrow \mathsf{H}(\neg b)$	$\mathsf{F}(a) \leftrightarrow \mathsf{F}(b)$
responded-existence(a, b)	$\mathsf{O}(a) \rightarrow \mathsf{O}(b)$	$\mathsf{F}(a) \rightarrow \mathsf{F}(b)$
response(a, b)	$(\neg a\, \mathsf{S}\, b) \vee \mathsf{H}(\neg a)$	$\mathsf{G}(a \rightarrow \mathsf{F}(b))$
precedence(a, b)	$\mathsf{H}(b \rightarrow \mathsf{O}(a))$	$(\neg b\, \mathsf{U}\, a) \vee \mathsf{G}(\neg b)$
succession(a, b)	response$(a, b) \wedge$ precedence(a, b)	
chain-response(a, b)	$\mathsf{H}(\mathsf{Y}(a) \rightarrow b) \wedge \neg a$	$\mathsf{G}(a \rightarrow \mathsf{X}(b))$
chain-precedence(a, b)	$\mathsf{H}(b \rightarrow \mathsf{Y}(a))$	$\mathsf{G}(\mathsf{X}(b) \rightarrow a) \wedge \neg b$
chain-succession(a, b)	$(\mathsf{H}(\mathsf{Y}(a) \rightarrow b) \wedge \neg a) \wedge \mathsf{H}(\mathsf{Y}(\neg a) \rightarrow \neg b)$	$\mathsf{G}(a \leftrightarrow \mathsf{X}(b))$
not-co-existence(a, b)	$\mathsf{O}(a) \rightarrow \neg\mathsf{O}(b)$	$\mathsf{F}(a) \rightarrow \neg\mathsf{F}(b)$
not-succession(a, b)	$\mathsf{H}(b \rightarrow \neg\mathsf{O}(a))$	$\mathsf{G}(a \rightarrow \neg\mathsf{F}(b))$
not-chain-succession(a, b)	$\mathsf{H}(b \rightarrow \neg\mathsf{Y}(a))$	$\mathsf{G}(a \rightarrow \neg\mathsf{X}(b))$

PDDL3 Operator	Equivalent PPLTL Formula	Equivalent LTL_f Formula
(at-end θ)	θ	$\mathsf{F}(\theta \wedge \mathsf{final})$
(always θ)	$\mathsf{H}(\theta)$	$\mathsf{G}(\theta)$
(sometime θ)	$\mathsf{O}(\theta)$	$\mathsf{F}(\theta)$
(sometime-after θ_1 θ_2)	$(\neg\theta_1\, \mathsf{S}\, \theta_2) \vee \mathsf{H}(\neg\theta_1)$	$\mathsf{G}(\theta_1 \rightarrow \mathsf{F}(\theta_2))$
(sometime-before θ_1 θ_2)	$\mathsf{H}(\theta_1 \rightarrow \mathsf{Y}(\mathsf{O}(\theta_2)))$	$\theta_2\, \mathsf{R}\, \neg\theta_1$
(at-most-once θ)	$\mathsf{H}(\theta \rightarrow (\theta\, \mathsf{S}\, (\mathsf{H}(\neg\theta) \vee \mathsf{start})))$	$\mathsf{G}(\theta \rightarrow (\theta\, \mathsf{U}\, (\mathsf{G}(\neg\theta) \vee \mathsf{final})))$
(hold-during n_1 n_2 θ)	$\bigvee_{0 \leq i \leq n_1} (\theta \wedge \mathsf{Y}^i(\mathsf{start})) \vee \bigwedge_{n_1 < i \leq n_2} \mathsf{H}(\theta \vee \mathsf{WY}^i(\mathsf{Y}(true)))$	$\bigvee_{0 \leq i \leq n_1} \mathsf{X}^i(\theta \wedge \mathsf{final}) \vee \bigwedge_{n_1 < i \leq n_2} \mathsf{WX}^i(\theta)$
$*$ (hold-after n θ)	$\bigvee_{0 \leq i \leq n} (\theta \wedge \mathsf{Y}^i(\mathsf{start})) \vee \mathsf{O}(\theta \wedge \mathsf{Y}^{n+1}(\mathsf{O}(\mathsf{start})))$	$\bigvee_{0 \leq i \leq n} \mathsf{X}^i(\theta \wedge \mathsf{final}) \vee \mathsf{X}^{n+1}(\mathsf{F}(\theta))$

Contribution

In our work, using PPLTL goals, we introduce a linear encoding of classical planning for PPLTL goals into classical planning that preserves plan length

- Due to the LTLf nature, state-of-the-art encodings for LTLf are
  - Exponential, but preserves the plan length [Baier & McIlraith, 2006]
  - Polynomial, but increases the plan length [Torres & Baier, 2015]

Handling PPLTL Goals

Intuition: given the prefix of a trace, while LTLf must consider all possible extensions, PPLTL can simply be evaluated on the prefix (i.e., the history produced so far)

How?

Exploit the "fixpoint characterization" of temporal formulas [Gabbay et al., 1980; Manna 1982; Barringer et al., 1989; Emerson 1990]

$$\mathsf{pnf}(p) = p;$$

$$\mathsf{pnf}(\mathsf{Y}\phi) = \boxed{\mathsf{Y}\phi;}$$

$$\mathsf{pnf}(\phi_1\, \mathsf{S}\, \phi_2) = \mathsf{pnf}(\phi_2) \vee (\mathsf{pnf}(\phi_1) \wedge \boxed{\mathsf{Y}(\phi_1\, \mathsf{S}\, \phi_2)});$$

$$\mathsf{pnf}(\phi_1 \wedge \phi_2) = \mathsf{pnf}(\phi_1) \wedge \mathsf{pnf}(\phi_2);$$

$$\mathsf{pnf}(\neg\phi) = \neg\mathsf{pnf}(\phi).$$

To evaluate a PPLTL formula, we only need to keep track of the truth value of *some* of its subformulas!!!

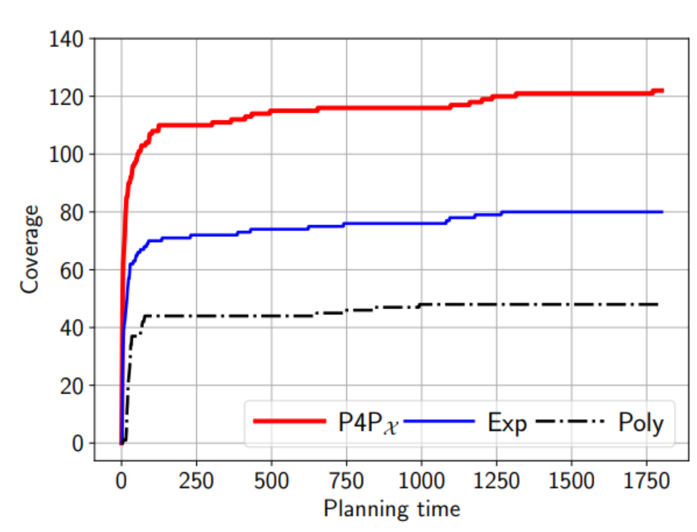
Evaluating PPLTL Goals

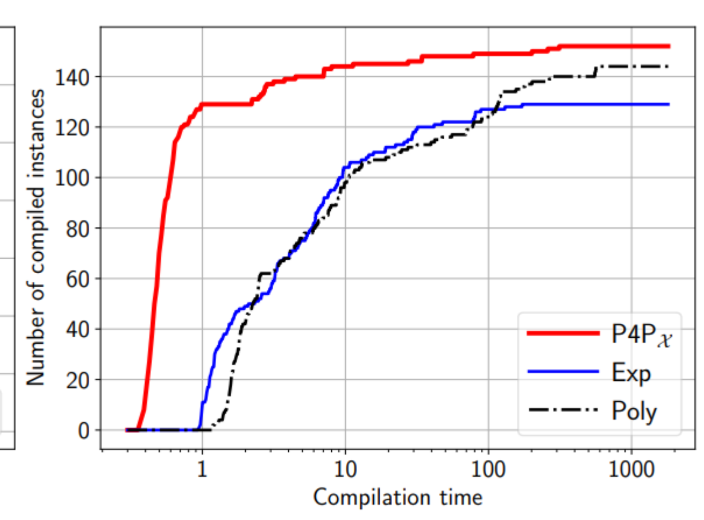
Sound and complete approach to symbolically encode PPLTL goal formulas in planning domains that is polynomial in the size of the domain specification and linear in the size of the PPLTL goal

Components	Encoding
Fluents $\mathcal{F}'$	$\mathcal{F}' := \mathcal{F} \cup \Sigma_\varphi$
Derived Predicates $\mathcal{F}'_{der}$	$\mathcal{F}'_{der} := \mathcal{F}_{der} \cup \{\mathsf{val}_\phi \mid \phi \in \mathsf{sub}(\varphi)\}$
Axioms $\mathcal{X}'$	$\mathcal{X}' := \mathcal{X} \cup \{x_\phi \mid \phi \in \mathsf{sub}(\varphi)\}$ where x_ϕ is $\begin{cases} \mathsf{val}_p \leftarrow p & (\phi = p) \\ \mathsf{val}_{\mathsf{Y}\phi'} \leftarrow \text{"}\mathsf{Y}\phi'\text{"} & (\phi = \mathsf{Y}\phi') \\ \mathsf{val}_{\phi_1 \mathsf{S} \phi_2} \leftarrow (\mathsf{val}_{\phi_2} \vee (\mathsf{val}_{\phi_1} \wedge \text{"}\mathsf{Y}(\phi_1\, \mathsf{S}\, \phi_2)\text{"})) & (\phi = \phi_1\, \mathsf{S}\, \phi_2) \\ \mathsf{val}_{\phi_1 \wedge \phi_2} \leftarrow (\mathsf{val}_{\phi_1} \wedge \mathsf{val}_{\phi_2}) & (\phi = \phi_1 \wedge \phi_2) \\ \mathsf{val}_{\neg\phi'} \leftarrow \neg\mathsf{val}_{\phi'} & (\phi = \neg\phi') \end{cases}$
Action Labels A	$A := A$, i.e., unchanged
Preconditions pre	$pre(a) := pre(a)$ for every $a \in A$, i.e., unchanged
Effects eff'	$\mathit{eff}'(a) := \mathsf{eff}(a) \cup \mathsf{eff}_{\mathsf{val}}$, where $\mathsf{eff}_{\mathsf{val}} = \{\mathsf{val}_\phi \rhd \{\text{"}\mathsf{Y}\phi\text{"}\}, \neg\mathsf{val}_\phi \rhd \{\neg\text{"}\mathsf{Y}\phi\text{"}\} \mid \text{"}\mathsf{Y}\phi\text{"} \in \Sigma_\varphi\}$
Initial State s'_0	$s'_0 := \sigma_0 \cup s_0$
Goal G'	$G' := \mathsf{val}_\varphi$

Experimental Results

- Introduce the Plan4Past[1] (P4P) system (github.com/whitemech/Plan4Past)
- IPC domains: BLOCKS, ELEVATOR, OPENSTACKS, ROVERS
- P4P + LAMA, Exp + LAMA Poly + LAMA





Domain		I	Coverage P4P	Coverage Poly	Coverage Exp	Avg RT P4P	Avg RT Poly	Avg RT Exp	Avg PL P4P	Avg PL Poly	Avg PL Exp
ROVERS	TB	7	**7**	**7**	6	**1.43**	21.11	1.98	**5.33**	5.67 (74.50)	**5.33**
	BF	40	**33**	6	22	35.36	–	**24.24**	43.68	–	**43.50**
BLOCKSWORLD	TB	15	**15**	**15**	8	**1.41**	20.43	13.13	7.50	7.88 (132.88)	**7.25**
	BF	21	**21**	1	1	–	–	–	–	–	–
OPENSTACKS	TB	10	**10**	**10**	6	**6.11**	31.66	8.75	22.00	**21.67** (349.00)	22.00
	BF	30	7	5	**8**	**11.88**	68.86	19.50	**24.00**	**24.00** (841.00)	**24.00**
ELEVATOR	BF	29	**29**	4	**29**	231.83	–	**228.09**	**75.48**	–	**75.48**
Total			**122**	48	80						