

# On Total-Order HTN Plan Verification with Method Preconditions

## – An Extension of the CYK Parsing Algorithm

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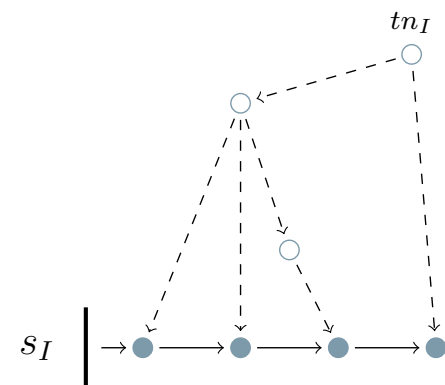
### Introduction

**Objective:** Our objective is to develop a novel Total Order HTN (TOHTN) plan verification approach by extending the CYK-parsing Algorithm which can deal with method preconditions.

**Motivations:** 1) TOHTN plan verification can be used in many applications, e.g., in verifying plans in IPC on HTN Planning, and 2) the current SOTA parsing-based TOHTN plan verification approach relies on a brute force search.

### TOHTN Planning

A TOHTN planning problem  $\mathcal{P} = ((\mathcal{F}, \mathcal{A}, \mathcal{C}, \delta, \mathcal{M}), c_I, s_I)$ :



- $\mathcal{F}$ : A set of propositions
- $\mathcal{A}$ : A set of primitive tasks
- $\mathcal{C}$ : A set of compound tasks
- $\delta : \mathcal{A} \rightarrow 2^{\mathcal{F}} \times 2^{\mathcal{F}} \times 2^{\mathcal{F}}$
- $\mathcal{M} \subseteq 2^{\mathcal{F}} \times \mathcal{C} \times (\mathcal{A} \cup \mathcal{C})^*$ : A set of methods
- $c_I \in \mathcal{C}$ : The initial task
- $s_I \in 2^{\mathcal{F}}$ : The initial state

**Solution:** A solution to a TOHTN planning problem is an action sequence into which is decomposed from the initial task by methods, it is executable in the initial state, and the precondition of every used method is satisfied.

### TOHTN Planning Problems and CFGs

The basis for using the CYK algorithm in TOHTN plan verification is the connection between TOHTN planning problems and context-free grammars (CFGs):

- A primitive task is a terminal symbol
- A compound task is a non-terminal symbol
- A method **without** preconditions is a production rule

**Idea:** We need to check whether the precondition of each method is satisfied when constructing the CYK table.

### TOHTN Plan Verification Algorithm

**Input:** A plan  $\pi = \langle p_1 \dots p_n \rangle$

A planning problem  $\mathcal{P}$  in 2RF

**Output:** True or false depending on whether  $\pi$  is a solution to  $\mathcal{P}$

- 1:  $\triangleright$  Let  $\langle s_0 \dots s_n \rangle$  be the state sequence *s.t.*  
 $s_0 = s_I$ , and  $s_{i-1} \rightarrow_{p_i} s_i$  for each  $i \in \{1 \dots n\}$
- 2: **for**  $i \leftarrow n$  to 1
- 3:  $A[i, i] = \{c \mid c \rightarrow \langle p_i \rangle\} \cup \{p_i\}$
- 4: **for**  $j \leftarrow i$  to  $n$
- 5: **for**  $k \leftarrow i$  to  $j - 1$
- 6: **for**  $m \in \left\{ m \mid \begin{array}{l} m = (prec(m), c, tn), \\ tn = \langle c'_1 c'_2 \rangle, c'_1 \in A[i, k], \\ c'_2 \in A[k + 1, j] \end{array} \right\}$
- 7:  $\triangleright$  Checking the method precondition
- 8: **if**  $prec(m) \subseteq s_{i-1}$
- 9:  $A[i, j] \leftarrow A[i, j] \cup \{c\}$
- 10:  $\triangleright$  Finding the unit productions
- 11: **for**  $\bar{m} \in \left\{ \bar{m} \mid \begin{array}{l} c' \rightarrow_{\bar{m}}^* \langle c \rangle, c' \in N_c, \\ c \in A[i, j] \end{array} \right\}$
- 12: **if**  $prec(m) \subseteq s_{i-1}$  for each  $m$  in  $\bar{m}$
- 13:  $A[i, j] \leftarrow A[i, j] \cup \{c'\}$
- 14: **if**  $c_I \in A[1, n]$  **return** true
- 15: **else return** false

**Input:** An input TOHTN planning problem is in 2-regulation form (2RF) instead of Chomsky Normal Form (CNF) for the purpose of keeping the size of the planning problem small. In 2RF, every method contains **at most** two subtasks.

**Line 8–9:** Checking whether a method precondition is satisfied.

**Line 11–13:** Finding all unit productions leading to  $c \in A[i, j]$ .

### Empirical Evaluation

Benchmark	Instances	Parsing-based	Planning-based	SAT-based	CYK-based (Ours)
to-val	10961	9158 (83.55%)	<b>10881 (99.27%)</b>	Not support	10832 (98.82%)
to-inval	1406	1301 (92.53%)	1364 (97.01%)	Not support	<b>1406 (100.00%)</b>
to-val-no-mprec	11264	7889 (70.04%)	9679 (85.93%)	1036 (9.20%)	<b>9946 (88.30%)</b>
to-inval-no-mprec	1103	915 (82.96%)	900 (81.6%)	684 (62.01%)	<b>981 (88.94%)</b>

The benchmark sets are from the IPC 2020 on HTN Planning. We compared our approach with the parsing-based plan verification approach, the planning-based approach, and the SAT-based approach. We ran the experiments on the benchmark sets which respectively consist of planning problems with and without method preconditions.

### Runtimes

