Strong Temporal Planning with Uncontrollable Durations: a State-Space Approach

Supplementary Material

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Appendix

In this appendix we prove Theorem 1.

Lemma 1. *Given a STTP σ, let $\chi = \bigcup_{s \in \sigma} snap(action(s))$. σ is valid for a strong planning problem with temporal uncertainty if and only if the DTPU K created by Algorithm 2 with DR is SC.*

Proof. Clearly, K is defined over all and only the snap actions of the action appearing in σ.

First, we prove that if σ is valid, then K is SC. Let μ be the assignment to the controllable time points of K, defined as follows.

$$\mu(a) = \begin{cases} t(a) & \text{if } a \text{ is a start snap action} \\ t(A_{\vdash} + \delta(a)) & \text{if } a \text{ is the end of } A \in DA_c \end{cases}$$

We now prove that μ is a strong schedule for K. For the sake of contradiction, suppose it is not. Then, there exists a duration for the uncontrollable actions for which one of the free constraints in K is violated. It is impossible to violate a duration constraint, therefore one of the three constraints in Definition 7 must be violated for some $\bar{a}$. This is impossible, because $sigma$ is a valid plan and if we violate constraint 1 or constraint 2, it means that there the preconditions of the action in σ corresponding to $\bar{a}$ are unsatisfied, if we violate constraint 3, then the overall conditions of the action in σ corresponding to $\bar{a}$ are unsatisfied.

Now, we prove that if K is SC, σ is valid. Reversing the argument before, we assume to have a strong schedule μ for K, and we prove that setting each step s of sigma as follows, yields a valid STTP.

- $t(s) = \mu(action(s)_{\vdash})$
- $\delta(s) = \mu(action(s)_{\dashv}) - \mu(action(s)_{\vdash})$, if $action(s)$ is controllable.

For the sake of contradiction, assume that σ defined as above is not a valid STTP. Then there exists a temporal plan $\pi \in I_\sigma$ that is not a valid plan for the domain in which we removed temporal uncertainty as per Definition 6. If π is invalid, it is either causally unsound (inapplicable in the initial state, not simulable, not leading to the goal state) or it violates some temporal constraint of the domain. But π cannot be causally unsound, because it fulfills all the constraints of Definition 7; and it cannot violate a temporal constraints, because the only temporal constraints in the plan are the duration of actions that are encoded in K and fulfilled by μ. $\square$

The proof of Theorem 1 descends from Lemma 1.

Theorem 1. *Given a strong planning problem with temporal uncertainty admitting a valid STTP σ, if DR is used, Algorithm 2 terminates with a valid STTP.*

Proof. We assume that the classical planner employed in Algorithm 2 is sound and complete. Therefore, sooner or later it will produce the abstract plan $\chi = \bigcup_{s \in \sigma} snap(action(s))$ as it is a plan achieving the goal. Then, by Lemma 1, we know that the DR approach yields a strongly controllable DTPU, and therefore the algorithm terminates with a valid STTP. $\square$