Plan proximity: an enhanced metric for plan stability

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Abstract

Plans executed in the real world have to adapt to the differences between the expected and the observed state of the environment where is being executed. Planning strategies dealing with this adaptation process can be compared by looking at the plan proximity between the original plan and the plans that these strategies generate to replace it. Plan proximity measures the difference between these sequential plans and the expected outcome states of these plans. We present arguments to support the claim that plan proximity is a more informed metric than plan stability in order to compare planning strategies solving these adaptation to the environment of execution.

Introduction

Plan adaptation can be performed using different strategies. Different plan repair and re-planning techniques are being used in order to deal with a changing dynamic environment of execution.

Plan stability was proposed as a metric for comparing two plans generated with different planning strategies solving this adaptation process (Fox et al. 2006). This measure considered the missing actions from the reference and the extra actions on the test plan. However, it was relaxed on the ordering of these actions in the plan and it did not considered the outcomes of these plans.

In this paper we propose an extension of the plan stability measure that takes these two factors into account providing an enhanced vision of the difference between two plans. Our metric looks at the combined plan differences and the expected outcome state differences. For both cases, plan and outcome state, it takes the missing items from the reference and the extra items appearing in the test into account.

Plan Difference

Definition 1 *A plan π is an ordered list of actions of length n that is expected to transform the state of the environment of execution from an initial state I to a final state G.*

A reference plan π_1 and a test plan π_2 can be compared by looking at the different number of actions that they contain. However, the point at which these actions are performed is important during plan execution as it can drastically change the outcome of the plan. Ordering is, therefore, important when comparing two plans.

The 'diff' algorithm (Hunt and McIlroy 1976) solves the longest common subsequence problem, which is commonly used to find the lines that do not change between two files. This can be applied to compare two plans, finding the identically ordered items that are present between two plans. In Table 1 we can see an example of a reference and test plan with their longest common subsequence shown with aligned common items. The action missing from the test sequence, and the extra actions that the test sequence contains, are also shown.

Ref	Test	Missing	Extra
	Y		Y
A	A		
B		B	
C	C		
	Z		Z
D		D	

Table 1: A sequence of actions for a reference (A B C D) and a test (Y A C Z) plan, with their longest subsequence (A C) shown aligned, the missing actions (B D) and the extra actions (Y Z).

Definition 2 *Given a reference plan π_1 and a test plan π_2, the difference between π_1 and π_2, $D_p(\pi_1, \pi_2)$ is the number of missing actions m_p from the reference plan π_1 and the number of extra actions e_p from a test plan π_2 that do not appear in the longest common subsequence of actions.*

$$D_p(\pi_1, \pi_2) = m_p + e_p$$

The plan difference is normalized using the sum of the number of actions of the reference plan n_1 and the test plan n_2.

$$\hat{D}_p(\pi_1, \pi_2) = \frac{D_p(\pi_1, \pi_2)}{n_1 + n_2} \in [0; 1]$$

The $\hat{D}_p$ for Table 1 is $2 + 2/4 + 4 = 0.5$. Table 2 shows an example where plan stability and plan difference provide different interpretations. The plan stability measure would consider these two plans to be identical, as they contain the same actions. The plan difference measure, however, takes the ordering of the actions into account and returns a result of 0.5.

Ref	Test	Missing	Extra
A		A	
B	B		
	A		A

Table 2: A sequence of actions for a reference (A B) and a test (B A) plan, with their longest subsequence (B), the missing actions (A) and the extra actions (A).

State Difference

Definition 3 *A state s is a set of proposition facts describing a configuration of the environment of execution. Proposition facts are propositions of the domain model whose variables have been all grounded to objects in the environment of execution.*

The ordering of these propositions does not change the state. If m is the total number of proposition facts in the domain of execution, a state can be represented as a binary string of length m containing 1's on the position of the string that corresponds to the proposition facts that its configuration represents. From these representation, the difference between two states can be calculated using the Hamming distance (Hamming 1950). The Hamming distance between two strings of equal length is the number of positions for which the corresponding symbols are different.

Definition 4 *Given a reference state s_1 and a test state s_2 for a common environment of execution, the state difference can be calculated as the Hamming distance between the string representation of s_1 and s_2.*

$$D_s(s_1, s_2) = \sum_{i=1}^{m} x_i \text{ where } x_i = \begin{cases} 0 \text{ if } s_1(i) = s_2(i) \\ 1 \text{ otherwise} \end{cases}$$

The state difference is normalized using the string length m.

$$\hat{D}_s(s_1, s_2) = \frac{D_s(s_1, s_2)}{m} \in [0; 1]$$

Plan Proximity

The proximity between a reference plan and a test plan is the combination of the plan difference and the estimated final state difference.

Definition 5 *Given a reference plan π_1 and a test plan π_2, their plan proximity $PP(\pi_1, \pi_2)$ is the normalized balanced sum of the plan difference $D_p(\pi_1, \pi_2)$ and the state difference of the estimated final states that they are expected to produce $D_s(G_1, G_2)$.*

$$\begin{aligned} PP_\alpha(\pi_1, \pi_2) = \quad 1 \quad & -\alpha \cdot \hat{D}_p(\pi_1, \pi_2) \\ & -(1-\alpha) \cdot \hat{D}_s(G_1, G_2) \in [0; 1] \end{aligned}$$

where $\alpha \in [0; 1]$ represents a *balance factor* between plan and state difference. The logical default value of α would be 0.5. However, it will depend on the particular evaluation of plans for the different environments of execution. Plan proximity can be interpret as the percentage of similarity between two plans. It satisfies the distance function properties. In consequence, together with the set of possible plans for an environment of execution, makes up a metric space.

Dynamic Planning Problems

The dynamic planning problem represents the problem of adapting plans in a dynamic changing environment of execution.

Definition 6 *A dynamic planning problem is a tuple (I, G, π_0, I', G') where π_0 is a plan that achieves the goal G from the initial state I and I' is a new initial state from which the new goal state, G' , must be achieved.*

The Plan Proximity metric space can be used to compare different planning strategies aiming to solve the dynamic planning problem. Plans coming out of these strategies can be compared and verified against an original or reference plan (Patrón, Lane, and Petillot 2009).

Definition 7 *Given a dynamic planning problem (I, G, π_0, I', G'), a planning strategy, P_1 , achieves greater plan proximity than a planning strategy, P_2 , if the plans produced by P_1 and P_2 , π_1 and π_2 respectively, satisfy $PP(\pi_0, \pi_2) < PP(\pi_0, \pi_1)$.*

Conclusion

This paper presents a novel approach towards comparing different planning strategies solving the dynamic planning problem. We use the term 'plan proximity' to refer to a measure of the similarity between a reference plan and a test plan. This distance-based metric considers actions missing from the reference plan, extra actions added in the test plan, sequential ordering of the plans and the expected outcomes states of these plans. By taking all these factors into account, it can be claimed that plan proximity is more informed than plan stability in providing an enhanced view of comparing planning strategies in a dynamic environment.

References

Fox, M.; Gerevini, A.; Long, D.; and Serina, I. 2006. Plan stability: Replanning versus plan repair. In *Int. Conf. on Automated Planning and Scheduling.*

Hamming, R. W. 1950. Error detecting and error correcting codes. *Bell System Technical Journal 29* 2:147–160.

Hunt, J. W., and McIlroy, M. D. 1976. An algorithm for differential file comparison. *Computing Science Technical Report, Bell Laboratories 41.*

Patrón, P.; Lane, D.; and Petillot, Y. 2009. Continuous mission plan adaptation for autonomous vehicles: balancing effort and reward. In *4th Workshop on Planning and Plan Execution for Real-World Systems, 19th Int. Conf. on Automated Planning and Scheduling.*