Optimising the Stability in Plan Repair via Compilation

Alessandro Saetti, Enrico Scala
Dipartimento Ingegneria dell'informazione
University of Brescia (Italy)

Abstract

Plan repair is the problem of solving a given planning problem by using a solution plan of a similar problem. This paper presents the first approach where the repair has to be done optimally, i.e., we aim at finding a minimum distance plan from the input plan; we do so by introducing a simple compilation scheme that converts a classical planning problem into another where optimal plans correspond to plans with the minimum distance from an input plan. Our experiments using a number of planners show that such a simple approach can solve many problems optimally and more effectively than replanning from scratch for a large number of cases. Also, the approach proves competitive with LPG-adapt.

Motivation, Contribution

- Agents acting in real-worlds have to deal with uncertainty; when there is no model about the uncertainty, or the number of unexpected situations is not bounded, a solution is replanning, yet, repair can be much more effective
- Previous solutions to replanning have no guarantees that the recovered plan is the most stable, however, plan stability is important when humans have already validated the activities
- In this work we take the stability problem as a primary concern, and supply the first compilation-based method that produces plans which are optimally stable

Background: The Plan Repair Problem

Stability

Let π and π' be two plans, the distance D between π and π' is defined as

$$D(\pi,\pi') = |\pi \setminus \pi'| + |\pi' \setminus \pi|$$

Operator $\setminus$ is defined so that $\pi \setminus \pi'$ contains $m - l$ instances of action a iff π and π' respectively contain m and l instances of a and $m > l$; $\pi \setminus \pi'$ contains 0 instances of a otherwise.

Plan Repair Problem

Let $\mathcal{P} = \langle F, A, I, G, c\rangle$ a classical planning problem, and π some sequence of actions from A. A plan repair problem is $\langle \mathcal{P}, \pi\rangle$.

A solution for the plan repair problem is a sequence π' that solves $\mathcal{P}$. A solution π^* is optimal if it is such that

$$\pi^* = \underset{\pi' \text{ solves } \mathcal{P}}{\arg\min}\ D(\pi,\pi')$$

From Plan Repair to Classical Planning: The RESA Compiler

The Intuition

- Create a classical problem whose optimal solutions are optimal solutions for the repair planning problem
- Create a number of copies for each action in the plan
- Shape a cost function that keeps track of those actions undermining the optimality of the solution
- Use a number of additional predicates to monitor already executed actions

Formally

Let $\mathcal{P} = \langle F, A, I, G, c\rangle$ be a planning problem, and $\pi = \langle a_1, \ldots, a_n\rangle$ be a sequence of actions in A. Resa takes in input $\mathcal{P}$ and π, and generates a new planning problem $\mathcal{P}' = \langle F', A_0 \cup A_1 \cup A_2 \cup A_3 \cup \{switch\}, I', G', c'\rangle$ such that:

$$F' = F \cup \{w\} \cup \bigcup_{i \in \{1,\ldots,n\}} d_i \cup \bigcup_{a \in \pi} \{p_a^i \mid 0 \le i \le M(a)\}$$

$$I' = I \cup \{w\} \cup \bigcup_{a \in \pi} p_a^0$$

$$A_0 = \bigcup_{a_i \in \pi} \langle \mathrm{pre}(a) \wedge w \wedge p_a^{B(a,i)},$$
$$\mathrm{eff}(a) \cup \{p_a^{B(a,i)+1}, \neg p_a^{B(a)(i)}, d_i\}\rangle$$

$$A_1 = \bigcup_{a \in A \setminus set(\pi)} \langle \mathrm{pre}(a) \wedge w, \mathrm{eff}(a)\rangle$$

$$A_2 = \bigcup_{a \in set(\pi)} \langle \mathrm{pre}(a) \wedge w \wedge p_a^{M(a)}, \mathrm{eff}(a)\rangle$$

$$A_3 = \bigcup_{i \in \{1,\ldots,n\}} \langle \neg w \wedge \neg d_i, \{d_i\}\rangle$$

$$switch = \langle w, \{\neg w\}\rangle$$

$$G' = G \wedge \bigwedge_{i \in \{1,\ldots,n\}} d_i$$

$$c'(a) = \begin{cases} 0 & \text{if } a \in A_0 \cup \{switch\} \\ 1 & \text{if } a \in A_1 \cup A_2 \cup A_3 \end{cases}$$

Theoretical Results

Soundness, Completeness and Optimality

Let $\mathcal{R} = \langle \mathcal{P}, \pi\rangle$ be a plan repair problem. Resa transforms $\mathcal{R}$ into a problem $\mathcal{P}'$ that is solvable if and only if so is $\mathcal{R}$. Moreover, the optimal solution for $\mathcal{P}'$ equates to that of the solution for $\mathcal{R}$ that minimises the distance from π.

Proof Intuition: (Soundness) Actions do not alter the semantics of classical planning. (Completeness) For each plan in the transformed problem you can reconstruct one that is valid for the original problem. (Optimality) We add a positive cost only when (i) we do not apply an action from the original plan (ii) we apply an action not present in the input plan

Compilation Size

Resa is linear on the size of $\mathcal{R}$.

Proof Intuition: Observe that there are only $O(\pi)$ new predicates and actions.

Empirical Results

Settings

- We take all the domains and problems from the optimal and satisficing track of the IPC-18
- For each instance we generate three plan repair problems modifying the initial state by randomly executing 1, 2 and 5 actions
- As an input plan, we used the shortest plan among those generated during the competition (ties broken randomly)
- All experiments ran up to 1800 seconds with a memory cut of 8GB

Coverage Analysis

Optimal setting	A* (Blind)		A* (h_{max})		Delfi1	
Domain	RS	Resa	RS	Resa	RS	Resa
agricola (48)	0	**8**	0	**10**	**39**	14
caldera (45)	18	**45**	18	**45**	39	**45**
data-network (48)	16	**48**	27	**48**	39	**48**
nurikabe (42)	30	**37**	30	**42**	**36**	18
settlers (30)	19	**25**	22	**28**	25	**28**
spider (51)	**17**	**17**	19	**41**	29	**41**
termes (54)	**18**	9	9	**20**	**36**	35
D-1 (106)	39	**74**	42	**85**	**82**	**82**
D-2 (106)	42	**66**	43	**77**	**82**	76
D-5 (106)	37	**49**	40	**72**	**79**	71
Total (318)	118	**189**	125	**234**	**243**	229

Satisficing setting	Lama		BFWS	
Domain	RS	Resa	RS	Resa
agricola (48)	**37**	16	**16**	10
caldera (27)	**27**	**27**	**27**	**27**
data-network (57)	15	**55**	**28**	22
nurikabe (57)	31	**56**	31	**57**
settlers (57)	47	**54**	10	**15**
spider (54)	**48**	23	**35**	33
termes (48)	**42**	32	**26**	11
D-1 (116)	84	**89**	56	**59**
D-2 (116)	83	**86**	56	**60**
D-5 (116)	80	**88**	**61**	56
Total (348)	247	**263**	173	**175**

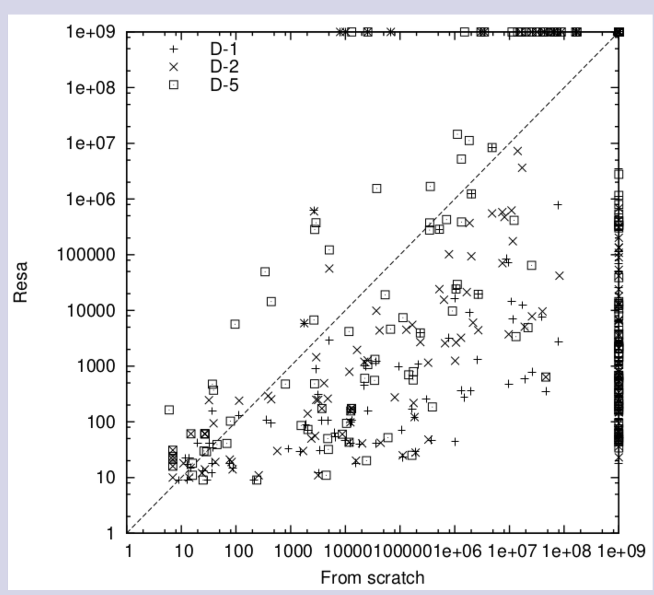
Table: Coverage Analysis. Each entry of the table corresponds to the number of problems solved by the system identified by the column using RS or Resa. D-{1,2,5} is a regrouping of the instances that considers all instances computed by injecting 1, 2, or 5 random actions in sequence. The number of problems is in parenthesis. Bolds are for best performers

Distance Analysis

	Optimal Setting						Satisficing Setting			
	A* (Blind)		A* (h_{max})		Delfi1		Lama		BFWS	
Domain	RS	Resa	RS	Resa	RS	Resa	RS	Resa	RS	Resa
agricola	–	–	–	–	30.00	**5.67**	49.20	**8.67**	52.25	**3.75**
caldera	7.89	**0.00**	8.56	**0.00**	3.97	**0.00**	21.52	**3.26**	24.11	**0.78**
data-network	6.13	**1.75**	7.56	**1.78**	8.85	**1.82**	107.20	**53.47**	85.64	**41.45**
nurikabe	17.03	**2.31**	16.23	**2.40**	14.92	**3.67**	65.48	**13.48**	83.35	**22.87**
settlers	9.94	**1.82**	11.50	**2.09**	8.88	**2.08**	110.04	**88.42**	83.29	**19.14**
spider	64.33	**1.67**	35.95	**11.32**	36.14	**11.79**	324.39	**245.09**	270.75	**233.36**
termes	18.56	**0.56**	19.78	**0.67**	29.10	**0.65**	**604.69**	1160.22	**575.00**	589.89

Table: Plan Distance Analysis. Each entry of the table corresponds to an average of the plan distances across problems solved by both RS and Resa. Bolds are for best performers

Node Expansion Analysis



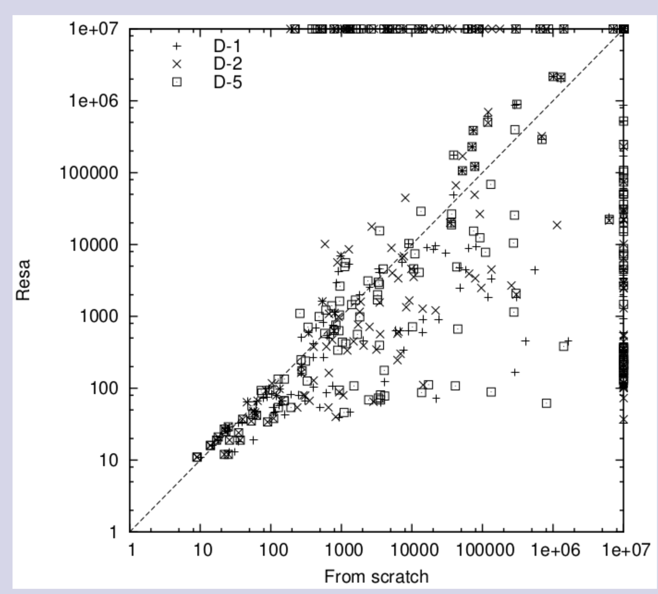


Figure: Scatter plotting the number of node expansions between Resa and replanning from scratch (RS). Each point is the pairwise comparison between Resa and RS with all optimal (left) and satisficing (right) planners. Full scale values are problems unsolved by one of the two systems.

Conclusion and Future Work

- Our results show that the approach is competitive with the state-of-the-art system LPG-adapt, while it is also capable of guaranteeing the optimality of the solution
- Future work includes to investigate different metrics for stability and adaptations of RESA to such metrics