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Relaxing the Relaxed Exist-Step Parallel Planning Semantics

What is Planning?

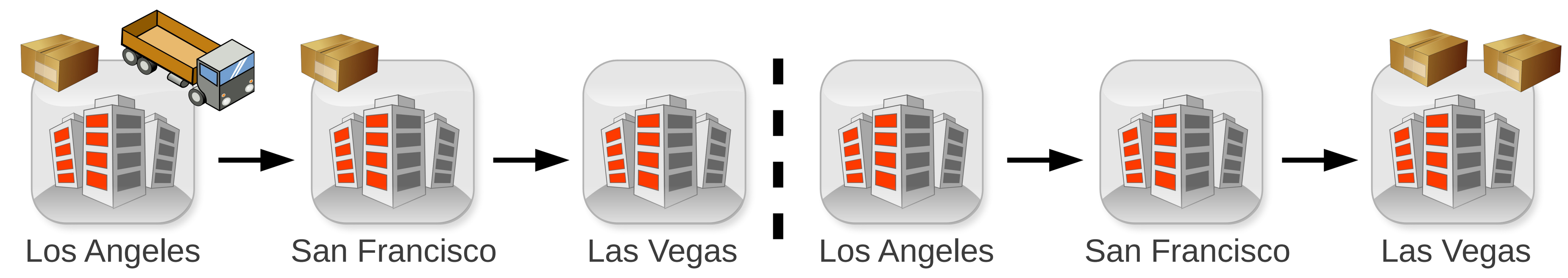
• World states are described as values of state variables
• Actions change the state of the world by changing the values of state variables by their effects
• Actions also have preconditions and are applicable only when their preconditions hold in the given state

Objective: given a set a of actions, an intial world state and the description of a goal state find a valid sequence of actions that transforms the world from the initial state to a goal state

Using SAT solvers to solve planning problems

• Construct a formula F_k such that it is satisfiable if and only if there is a plan of at most k steps
• Solve F_1, F_2, … using a SAT solver until you reach a satisfiable formula F_n
• Extract a plan from the satisfying assignment of F_n

Example: delivering 2 packages to Las Vegas



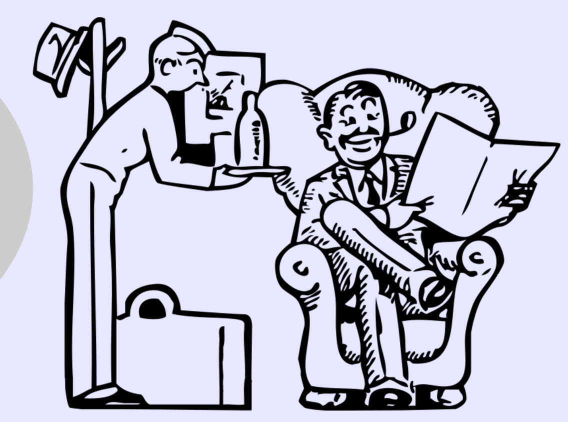
State Variables and their domains:
• Truck location T, dom(T)={LA, SF, LV}
• Package locations P and Q
dom(P) = dom(Q) = {LA, SF, LV, Tr}

Initial State: T=LA, P=LA, Q=SF
Goal State: P=LV, Q=LV

Actions:
• move(x,y)=[prec: {T=x}, eff: {T=y}]
• loadP(x)=[prec: {T=x, P=x}, eff: {P=Tr}]
• loadQ(x)=[prec: {T=x, Q=x}, eff: {Q=Tr}]
• dropP(x)=[prec: {T=x, P=Tr}, eff: {P=x}]
• dropQ(x)=[prec: {T=x, Q=Tr}, eff: {Q=x}]
Where x,y are LA, SF, and LV

Plan: loadP(LA), move(LA, SF), loadQ(SF), move(SF, LV), dropP(LV), dropQ(LV)

How to construct such a formula?
How many actions are in a step?
(step = set of actions)



Four possible answers: (parallel planning semantics)

The foreach step

• The preconditions of all actions in a step must already hold in the beginning of the step
• The effects of all actions must hold at the end of this step
• The actions in a step do not interfere – they cannot destroy each others preconditions by their effects
• The actions in a step can be turned into a valid subplan sequence

The exist step

• The preconditions of all actions in a step must already hold in the beginning of the step
• The effects of all actions must hold at the end of this step
• ~~The actions in a step do not interfere – they cannot destroy each others preconditions by their effects~~
• The actions in a step can be turned into a valid subplan sequence

The relaxed exist step

• ~~The preconditions of all actions in a step must already hold in the beginning of the step~~
• The effects of all actions must hold at the end of this step
• ~~The actions in a step do not interfere – they cannot destroy each others preconditions by their effects~~
• The actions in a step can be turned into a valid subplan sequence

Relaxed relaxed exist step

NEW

• ~~The preconditions of all actions in a step must already hold in the beginning of the step~~
• ~~The effects of all actions must hold at the end of this step~~
• ~~The actions in a step do not interfere – they cannot destroy each others preconditions by their effects~~
• The actions in a step can be turned into a valid subplan sequence

Example: shortest plans for different semantics

• **foreach** {loadP(LA)} ♦ {move(LA, SF)} ♦ {loadQ(SF)} ♦ {move(SF, LV)} ♦ {dropP(LV), dropQ(LV)} – 5 steps
• **exist** {loadP(LA), move(LA, SF)} ♦ {loadQ(SF), move(SF, LV)} ♦ {dropP(LV), dropQ(LV)} – 3 steps
• **relaxed exist** {loadP(LA), move(LA, SF), loadQ(SF)} ♦ {move(SF, LV), dropP(LV), dropQ(LV)} – 2 steps
• **relaxed relaxed exist** {loadP(LA), move(LA, SF), loadQ(SF), move(SF, LV), dropP(LV), dropQ(LV)} – 1 step

Conjectures

• Using a more relaxed semantics allows us to find plans with fewer steps
• Fewer steps means fewer SAT formulas to solve, which leads to finding plans faster

Basic ideas of the relaxed relaxed exist step SAT encoding

• The SAT encoding only approximates the semantics, i.e., the satisfiability of the constructed formula F_k implies the existence of a k-step plan (not vice versa)
• The actions are ranked using cycle–ignoring topological sorting on the action dependency graph (action ranking can be arbitrary as long as it is injective)
• The encoding allows only lower ranking actions before higher ranking ones in a step
• The encoding uses implication chains similar to those used in the exist step and relaxed exist step encoding

Experimental setting

• We compared 3 of the 4 encodings on eight International Planning Competition (IPC 2012) domains (20 problems each)
• All formulas were solved with the same SAT solver – Lingeling
• Computer: Intel i7 920 cpu @2.67 Ghz and 6 GB of memory
• The time limit was 30 minutes for a step
• We measured the number of problems that were solved within the time limit and the number of steps needed

Domain	Foreach Step		Exist Step		Relaxed Relaxed E.S.	
	Solved	Avg. Steps	Solved	Avg. Steps	Solved	Avg. Steps
Barman	8	46.3	8	36.6	14	14.8
Elevators	20	9.5	20	6.5	20	4.3
Parcprinter	20	13.5	20	13.5	20	1.5
Pegsol	7	22.8	13	24.0	19	8.6
Storage	15	9.2	19	7.9	19	4.3
Visitall	9	27.0	11	31.4	20	1.7
Woodwork	20	3.4	20	3.3	20	1.7
Zenotravel	16	5.9	16	4.5	15	2.7

Conclusion

• We have defined a novel parallel planning semantics and a SAT encoding which approximates it
• The results of the experiments show that the new encoding is successfull in solving IPC benchmark problems
• For the domains Pegsol, Barman, and Visitall we achieved a significant improvement in the number of solved instances
• The average number of required steps decreased for all domains, most significantly for the Visitall domain
• The encoding can be further improved to produce smaller formulas and to better approximate the defined semantics

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