GraphPlan - SatPlan

Manuela Veloso
Planning, Fall 2001

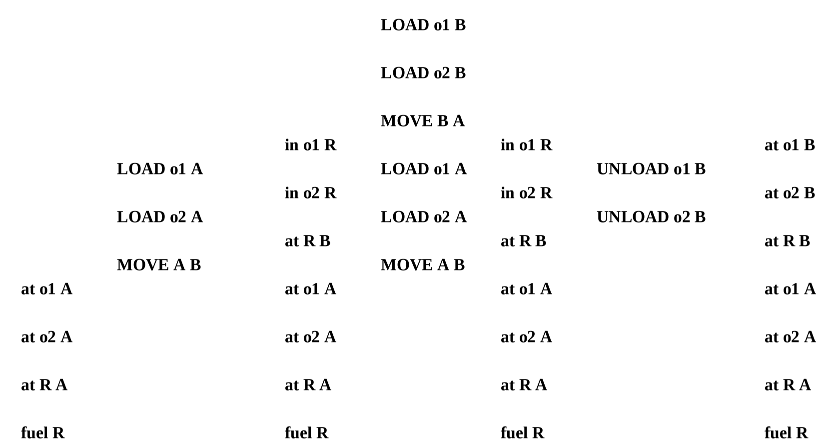
Graphplan

Blum & Furst 95

- Forward search combined with backward search.
- Uses planning graphs.
- Two stages:
  - ▷ Extend: One more time step in the planning graph.
  - ▷ Search: Is there a valid plan in the planning graph?
- Graphplan finds a plan or proves that no plan has fewer “time steps.”

Extending a Planning Graph

- To create an action-level i:
  - ▷ Add each instantiated operator, for which all of its preconditions are present at proposition-level i AND *no two of its preconditions are exclusive.*
  - ▷ Add all the no-op actions.
- Determine the exclusive actions.
- To create a proposition-level $i+1$:
  - ▷ Add all the effects of the inserted actions at action-level i - distinguishing add and delete effects.
- Determine the exclusive propositions.



Planning Graphs

- A literal may exist at level $i+1$ if it is an Add-Effect of some action in level i.
- Two propositions p and q are *exclusive* in a proposition-level if ALL actions that add p are exclusive of ALL actions that add q.
- Actions A and B are *exclusive* at action-level i, if:
  - ▷ Interference: A (or B) deletes a precondition or an Add-Effect of B (or A).
  - ▷ Competing Needs: p is a precondition of A and q is a precondition of B, and p and q are exclusive in proposition-level $i-1$.

Exclusivity Examples

- Exclusive Actions: (Move A B) deletes a precondition of (Load o1 A). Therefore exclusive (existence of threats).
- Exclusive Propositions: (at R A) and (at R B) at time 2 are exclusive. (at R A) is added by a no-op and (at R B) is added by (Move A B) and no-op and (Move A B) are exclusive actions.
- Exclusive Actions: Then (Load o1 A) and (Load o2 B) are exclusive because (at R A) and (at R B) are exclusive.
- Propositions can be exclusive in some time step and not in others: If (at o1 A) and (at R A) at time 1, then (in o1 A) and (at R B) are exclusive at time 2, but not at time 3.

Searching a Planning Graph

- Level-by-level backward-chaining approach to use the exclusivity constraints.
- Given a set of goals at time t, identify all the sets of actions (including no-ops) at time $t-1$ who add those goals and are not exclusive. The preconditions of these actions are new goals for $t-1$.

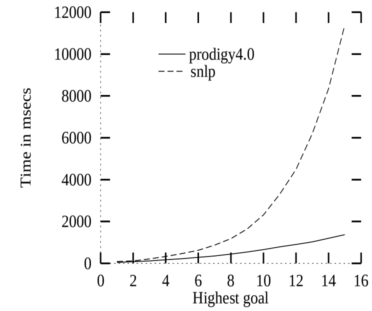
Planning as Satisfiability

- One interpretation: "first-order deductive theorem-proving does not scale well."
- One solution: "propositional satisfiability"
- Uniform clausal representation for goals and operators.
- Stochastic local search is a powerful technique for planning.

SatPlan

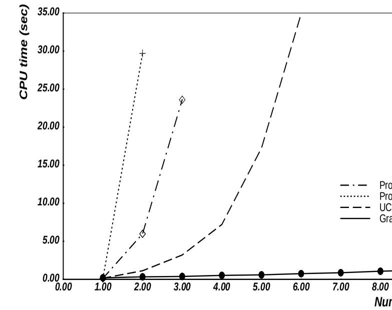
- Assume the plan has *n* (time-parallel) steps. *(strong assumption)*
- Initial state: completely specified at time 0. at-o1-A_0 ∧ at-o2-A_0 ∧ at-R-A_0
- Goal: specified at time $2n$. at-o1-B_6 ∧ at-o2-B_6
- Actions: specified at *odd* times; An action implies its preconditions and effects. (¬load-o1-A_1 ∨ at-o1-A_0) ∧ (¬load-o1-A_1 ∨ at-R-A_0) ∧ (¬load-o1-A_1 ∨ in-R-A_2) ∧ (¬load-o1-A_1 ∨ ¬at-o1-A_2)

Performance



Nonlinear state-space planning can suffer from goal orderings, but can use state information to reduce the search space

Veloso et al.



Graph-based planning com forward state expansio and exclusivity analys with backwards goal se

Blum et al.

Performance (cont.)

Prob	UMOP OBDDs		Prodigy4.0 NL state		STAN graphplan		HSP A* heuristics		IPP graphplan		Blackbox satplan	
1	20	11	80	15	46	11	2007	13	50	15	113	11
2	150	17	200	23	1075	17	2150	21	380	23	7820	17
3	710	23	210	31	54693	23	2485	31	3270	31	-	-
4	1490	29	370	39	3038381	29	3060	37	26680	39	-	-
5	3600	35	430	47	-	-	3320	47	226460	47	-	-
6	7260	41	590	55	-	-	3779	53	-	-	-	-
7	13750	47	800	63	-	-	4797	63	-	-	-	-
8	23840	53	960	71	-	-	5565	71	-	-	-	-
9	36220	59	1240	79	-	-	6675	79	-	-	-	-
10	56200	65	1560	87	-	-	7583	85	-	-	-	-
11	84930	71	1820	95	-	-	9060	93	-	-	-	-
12	127870	77	2240	103	-	-	10617	101	-	-	-	-
13	197170	83	2660	111	-	-	12499	109	-	-	-	-
14	290620	89	3200	119	-	-	15050	119	-	-	-	-
15	411720	95	3740	127	-	-	16886	125	-	-	-	-
16	549610	101	4350	135	-	-	20084	135	-	-	-	-
17	746920	107	5030	143	-	-	23613	143	-	-	-	-
18	971420	113	5900	151	-	-	26973	151	-	-	-	-
19	1361580	119	6810	159	-	-	29851	157	-	-	-	-
20	1838110	125	7710	167	-	-	33210	165	-	-	-	-

planning time in ms; number of plan steps

UMOP: Jensen & Veloso (CMU); **HSP**: Geffner & Bonet (Simon Bolivar Univ, Venezuela);
STAN: Long & Fox (Durham Univ, UK); **IPP**: Köhler (Freiburg Univ, Germany);
Blackbox: Kautz & Selman (AT&T, Cornell Univ)

Performance (cont.)

Prob	UMOP OBDDs		Prodigy4.0 NL state		STAN graphplan		HSP A* heuristics		IPP graphplan		Blackbox satplan	
1	20	7	30	7	19	7	2121	7	10	7	11	7
2	20	7	70	7	18	7	2104	7	10	7	12	7
3	20	7	30	7	19	7	2144	7	10	7	14	7
4	20	7	40	7	20	7	2188	7	10	7	16	7
5	20	7	30	7	21	7	2208	7	10	7	18	7
6	20	7	40	7	22	7	2617	7	10	7	20	7
7	30	7	50	7	22	7	2316	7	20	7	22	7
8	10	7	40	7	23	7	2315	7	20	7	24	7
9	20	7	50	7	25	7	2357	7	-	-	26	7
10	30	7	80	7	26	7	2511	7	10	7	29	7
11	10	7	60	7	27	7	2427	7	30	7	30	7
12	20	7	60	7	28	7	2456	7	30	7	32	7
13	20	7	90	7	29	7	3070	7	20	7	36	7
14	20	7	60	7	31	7	2573	7	30	7	35	7
15	20	7	100	7	32	7	2577	7	30	7	38	7
16	20	7	70	7	34	7	2699	7	10	7	39	7
17	20	7	100	7	35	7	2645	7	30	7	41	7
18	20	7	90	7	37	7	2686	7	10	7	43	7
19	20	7	110	7	39	7	2727	7	30	7	45	7
20	20	7	90	7	40	7	2787	7	20	7	47	7

planning time in ms; number of plan steps

Performance (cont.)

Prob	STAN graphplan		HSP A* heuristics		IPP graphplan		Blackbox satplan	
1	767	27	79682	43	900	26	2062	27
2	4319	32	97114	44	-	-	6436	32
5	364932	29	144413	26	2400	24	-	-
7	-	-	788914	112	-	-	-	-
11	12806	34	86195	30	6940	33	6544	32

planning time in ms; number of plan steps

▷ UMOP needs tractable representation (on-going research).

▷ Prodigy needs control knowledge (planning by analogy or control rules).

Summary

- Disjunctive reasoning in Graphplan
- Complete plans in SatPlan
- Next class OBDD-based planning