Symbolic Search for Oversubscription Planning

David Speck[1] and Michael Katz[2] – speckd@informatik.uni-freiburg.de, michael.katz1@ibm.com

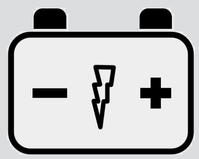
[1]University of Freiburg, [2]IBM T.J. Watson Research Center

Motivation

Multiple Goals

Pictures by NASA/JPL/Cornell University

Limited Resources



Achieve the highest utility respecting the limited resources.

⇝ **Contribution**: Application of **symbolic search**.

Oversubscription Planning (OSP)

An **OSP task** is a 6-tuple $\Pi = \langle \mathcal{V}, s_0, \mathcal{O}, c, u, b \rangle$.

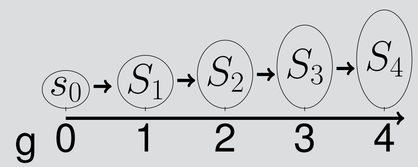
- $\mathcal{V}$: set of finite-domain **state variables**
- s_0: **initial state** over $\mathcal{V}$
- $\mathcal{O}$: set of **operators** $o = \langle pre_o, eff_o \rangle \in \mathcal{O}$
- $c : \mathcal{O} \mapsto \mathbb{N}_0$: operator **cost**
- $u : \mathcal{S} \mapsto \mathbb{N}_0$: **utility function** defined for each possible state
  - ⇝ e.g., multiple goals with different utilities
- $b \in \mathbb{N}_0$: **cost bound** for plans
  - ⇝ limited resources
- operator cost and utility are **not comparable**

OSP Plan

- applicable **sequence of operators** $\pi = \langle o_0, \dots, o_{n-1} \rangle$
- **plan cost** $c(\pi) \leq b$ (cumulative operator cost)
- **plan utility** $u(\pi) \triangleq$ utility of the **end state** $u(s_0[\pi])$
- **optimality**: **highest utility** among all plans

Symbolic Search for Classical Planning

- operations on **sets of states**
- $S \subseteq \mathcal{S}$ represented by **characteristic function** χ_S
  - e.g., $S \cap S' \triangleq \chi_S \wedge \chi_{S'}$
- Binary Decision Diagrams (BDDs)

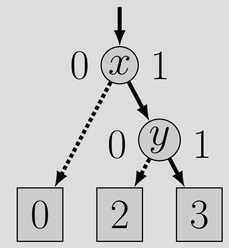


SYM-OSP – Symbolic Search for OSP

- perform forward **symbolic blind search**
  - **similar** to symbolic search for **classical planning**
- evaluate **utility values of states** that are expanded
  - u as **ADD**: multiplication + maximum
  - u as **BDDs**: multiple intersections
- **termination** criteria
  - state with **highest possible utility** is found
  - all **reachable states** within b are expanded

- SYM-OSP is **sound**, **complete** and **optimal**.
- SYM-OSP finds **cheapest** utility-optimal plans.

Utility Function as Algebraic Decision Diagram (ADD)



- $u(x, y) = 2x + xy$
- alternative: **multiple BDDs**

Experiments

Algorithm	SYM-OSP		$A^{\star}_{uADD}$	$A^{\star}_{mc}$			BnB	
Benchmark Set (# Inst.)	uBDD	uADD	h_{blind}	h_{blind}	h^{b}_{max}	$h^{b}_{m\&s}$	h_{blind}	h^{mc}_{lmcut}
25% Bound (1667)	1271	**1274**	1165	1197	1190	1074	1183	1151
50% Bound (1667)	990	**993**	860	901	902	828	893	867
75% Bound (1667)	**866**	862	718	758	738	734	735	702
100% Bound (1667)	**802**	793	629	668	655	676	643	618
Overall (6668)	**3929**	3922	3372	3524	3485	3312	3454	3338

- **symbolic search** performs **best overall**
- exploits **compact representation** of **DDs**
- **future work**: symbolic **backward search** for OSP