Classical Planning Algorithms

3. Planning Algorithms

Malte Helmert

ICAPS 2018 Summer School

June 21, 2018

The Big Three

Classical Planning Algorithms

In This Part

very high-level overview of classical planning algorithms

- bird's eye view: no details, just some very brief ideas
- some in-depth coverage in Gabi's presentation tomorrow
- basic literature pointers provided, but please get in touch during or after the summer school if you want more!

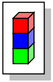
The Big Three

Of the many planning approaches, three techniques stand out:

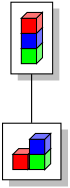
1. heuristic state-space search
2. SAT planning
3. symbolic search

Heuristic State-Space Search

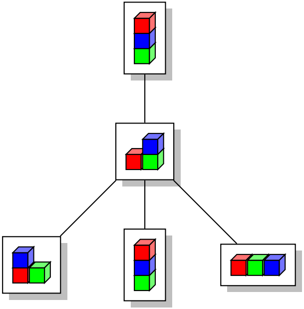
State-Space Search in a Nutshell



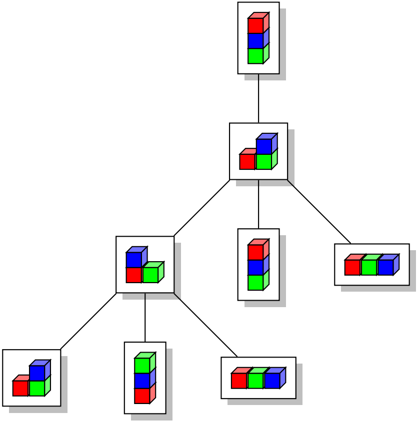
State-Space Search in a Nutshell



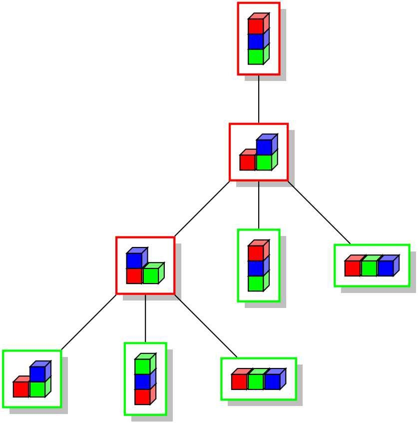
State-Space Search in a Nutshell



State-Space Search in a Nutshell



State-Space Search in a Nutshell



Closed node

Open node

Which open node should we select for expansion?

Heuristic Search

- prioritize open nodes with heuristic
- heuristic
  - estimates cost of path from state to closest goal state
  - $h : S \to \mathbb{R}_0^+$
- search algorithms differ in how they exploit the heuristic:
  - h: heuristic estimate of state
  - g: cost of path from initial state to open node
  - greedy best-first search: expand node with minimum h
  - A^*: expand node with minimum $g + h$

Planning Heuristics

The central question for heuristic search approaches to classical planning:

How do we find good heuristics in a domain-independent way?

$\rightsquigarrow$ Gabi's presentation tomorrow

SAT Planning

SAT Planning: Basic Ideas

- formalize problem of finding plan with a given horizon (length bound) as a propositional satisfiability problem and feed it to a generic SAT solver
- to obtain a (semi-) complete algorithm, try with increasing horizons until a plan is found (= the formula is satisfiable)
- important optimization: allow applying several non-conflicting actions "at the same time" so that a shorter horizon suffices

SAT Formulas: Variables

- assume STRIPS encoding $\langle V, I, G, A \rangle$
- given horizon $T \in \mathbb{N}_0$

Variables of SAT Encoding

- propositional variables v^i for all $v \in V$, $0 \leq i \leq T$ encode state after i steps of the plan
- propositional variables a^i for all $a \in A$, $1 \leq i \leq T$ encode actions applied in i-th step of the plan

SAT Formulas: Clauses

- assume STRIPS encoding $\langle V, I, G, A \rangle$
- given horizon $T \in \mathbb{N}_0$

Clauses of SAT Encoding

- unit clauses encoding initial state:
  v^0 for all $v \in I$ and $\neg v_0$ for all $v \notin I$
- unit clauses encoding goal:
  v^T for all $v \in G$
- ...

SAT Formulas: Clauses

- assume STRIPS encoding $\langle V, I, G, A \rangle$
- given horizon $T \in \mathbb{N}_0$

Clauses of SAT Encoding

for all $1 \leq i \leq T$:

- subformulas encoding action preconditions:
  $a^i \rightarrow \bigwedge_{v \in pre(a)} v^{i-1}$
- subformulas encoding action conflicts:
  $\neg(a^i \wedge b^i)$ for all $a, b \in A$ with $a \neq b$, $add(a) \cap del(b) \neq \emptyset$
- subformulas encoding successor states:
  $v^i \leftrightarrow \left(\bigvee_{a \in A : v \in add(a)} a^i \vee (v^{i-1} \wedge \neg \bigvee_{a \in A : v \in del(a)} a^i)\right)$

Advanced SAT Planning

Much fancier SAT encodings and SAT planning techniques exist.

- e.g., Madagascar planner (Rintanen, IPC 2011 & 2014)
- many papers by Jussi Rintanen (e.g., Rintanen; AIJ 2012)
- related: property-directed reachability (Suda, JAIR 2014)

Symbolic Search

Symbolic Search Planning: Basic Ideas

- search processes sets of states at a time
- operators, goal states, state sets reachable with a given cost etc. represented by binary decision diagrams (BDDs) (or related data structures)
- hope: exponentially large state sets can be represented as polynomially sized BDDs, which can be efficiently processed
- perform symbolic Dijkstra search on these set representations

Symbolic Breadth-First Progression Search

simple symbolic search for unit-cost problems:

Progression Breadth-first Search

def bfs-progression(V, I, O, G):
    $goal\_states := conjunction(G)$
    $reached_0 := \{I\}$
    $i := 0$
    loop:
        if $reached_i \cap goal\_states \neq \emptyset$:
            return solution found
        $reached_{i+1} := reached_i \cup apply(reached_i, O)$
        if $reached_{i+1} = reached_i$:
            return no solution exists
        $i := i + 1$

Symbolic Breadth-First Progression Search

simple symbolic search for unit-cost problems:

Progression Breadth-first Search

def bfs-progression(V, I, O, G):
- $goal\_states := conjunction(G)$
- $reached_0 := \{I\}$
- $i := 0$
- **loop**:
  - **if** $reached_i \cap goal\_states \neq \emptyset$:
    - **return** solution found
  - $reached_{i+1} := reached_i \cup apply(reached_i, O)$
  - **if** $reached_{i+1} = reached_i$:
    - **return** no solution exists
  - $i := i + 1$

$\rightsquigarrow$ If we can implement operations *conjunction*, $\{I\}$, $\cap$, $\neq \emptyset$, $\cup$, *apply* and $=$ efficiently, this is a reasonable algorithm.

Symbolic Search Planning: Some Pointers

- symbolic planning systems:
  - Gamer (Edelkamp & Kissmann, IPC 2008)
  - SymBA* (Torralba et al., IPC 2014)
- comprehensive treatment:
  Álvaro Torralba's PhD thesis (Torralba, 2015)
- red-hot paper using EVMDDs for symbolic search
  at ICAPS next week (Speck et al., 2018)

Summary

Summary

three major algorithmic approaches to classical planning:

- heuristic state-space search
- SAT planning
- symbolic search