On the Role of Ground Actions in Refinement Planning

Håkan L. S. Younes and Reid G. Simmons
Carnegie Mellon University
Least-commitment Planning

- Record only essential step orderings and variable bindings
  - SNLP (McAllester & Rosenblitt 1991)
  - UCPOP (Penberthy & Weld 1992)
- Leads to a reduced branching factor
- Remained inefficient despite much effort in the first part of the 90’s
Paradigm Shift

- Reachability analysis
  - Graphplan (Blum & Furst 1995)
- Planning as propositional satisfiability
  - SATPLAN (Kautz & Selman 1996)
- Heuristic search planning
  - HSP (Bonet & Geffner 1998)
  - FF (Hoffman & Nebel 2001)

All these planning systems work with ground actions
Revival of Partial Order Planning

- RePOP (Nguyen & Kambhampati 2001)
  - Use distance based heuristics and reachability analysis with UCPOP
  - Only ground actions!

Is there some inherent power in planning with ground actions?
Contents of This Talk

- Identify key benefits of ground actions
- Use this insight to improve planning with partially instantiated actions

Least commitment planning is not dead!
Benefits of Ground Actions

- Early commitment of parameter bindings of actions
- Enforcement of \textit{joint parameter domain constraints} of actions
Early Commitment of Parameter Bindings

- Makes detecting inconsistencies easier

Example:

- Action 1: (clear ?x)
- Action 2: (clear ?x)
- Action 3: (not (clear ?y))
Early Commitment of Parameter Bindings

- Makes detecting inconsistencies easier

Is there a consistent assignment?

Graph coloring: Hard problem!
Benefits of Ground Actions

- Early commitment of parameter bindings of actions
- Enforcement of joint parameter domain constraints of actions
Joint Parameter Domain Constraints

- Feasible instantiations of (drive ?truck ?from ?to):
  - (drive truck airport city)
  - (drive truck city airport)

- Joint parameter domain constraints:

(drive ?truck ?from ?to):

\{truck, airport, city\}
\{truck, city, airport\}
Updating Joint Parameter Domain Constraints

(drive ?truck ?from ?to):

\(\langle \text{truck, airport, city} \rangle\)
\(\langle \text{truck, city, airport} \rangle\)

Binding constraint: 
?from = airport
Contents of This Talk

- Identify key benefits of ground actions
- Use early commitment of parameter bindings and joint parameter domain constraints to improve planning with partially instantiated actions
Partial Order Planning

- In each iteration of POP algorithm:
  - Select a plan to expand
  - Select flaw
    - threatened causal link
    - unachieved precondition
  - Repair flaw
Implementing Early Commitment of Parameter Bindings

- Implement it as **flaw selection strategy**
  - Select static preconditions first

- **Rationale:**
  - Static preconditions must be linked to the initial conditions
  - The initial conditions contain no variables
  - Therefore, linking static preconditions will bind action parameters to objects
Implementing Joint Parameter Domain Constraints

- Add joint parameter domain constraints to binding constraints of the plan
Empirical Evaluation

- Hypothesis:
  - Should explore about as many plans as when using ground actions
  - Should generate fewer plans
Blocks World Domain

Initial state: \( b_1 \ b_2 \ \cdots \ b_n \)

Goal state: \( b_n \d \ b_2 \ b_1 \)
Results in Blocks World Domain

- Generated plans (ground actions)
- Generated plans (partially instantiated actions)
- Explored plans (both cases)
Search Tree in Blocks World Domain

Ground actions

- initial cond.
- (unstack b_1)
- ... (unstack b_{i-1})
- (unstack b_{i+1})
- ... (unstack b_n)

Partially instantiated actions

- initial cond.
- (unstack ?b)
Relative Performance

- Performance partially instantiated/Performance ground

<table>
<thead>
<tr>
<th>Domain</th>
<th>Generated plans</th>
<th>Explored plans</th>
<th>Planning time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks world</td>
<td>0.04-0.77</td>
<td>1.0</td>
<td>0.54-1.0</td>
</tr>
<tr>
<td>Gripper</td>
<td>0.43-0.52</td>
<td>1.0</td>
<td>2.2-2.6</td>
</tr>
<tr>
<td>Logistics</td>
<td>0.80-1.0</td>
<td>1.0-1.2</td>
<td>6.7-12.0</td>
</tr>
</tbody>
</table>
Grid World Domain

Key destination

Key

Robot start and goal position
New Flaw Selection Strategy

- “Least Cost Flaw Repair” (Joslin & Pollack 1994)
  - Selects a flaw that can be repaired in the least number of ways
Results in Grid World Domain

- Using LCFR and partially instantiated actions
  - Generated/explored plans: 3,704/3,084
  - Planning time: 3.76 seconds

- Using LCFR and ground actions
  - Generated/explored plans: >100,000/>60,000 (search limit reached)
  - Planning time: >19.8 seconds
Conclusions

- Ground actions give us two things
  - Early commitment of parameter bindings
  - Joint parameter domain constraints
- We can use insight to improve POP
  - Reduces branching factor of search space
- Using partially instantiated actions can dramatically reduce planning time
Future Work

- Better understand when planning with partially instantiated actions can be beneficial
- Experiment with other flaw selection strategies
  - Flaw selection is the key strength of VHPOP
VHPOP: Versatile Heuristic Partial Order Planner

www.cs.cmu.edu/~lorens/vhpop.html