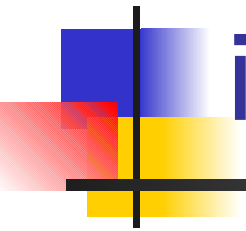
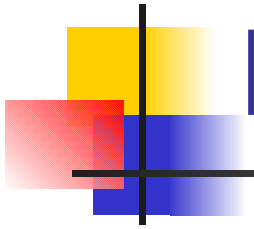


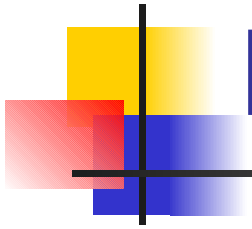
On the Role of Ground Actions in Refinement Planning

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

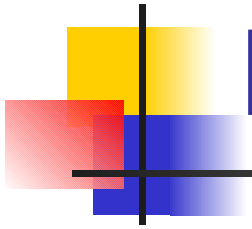


Paradigm Shift

- 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)

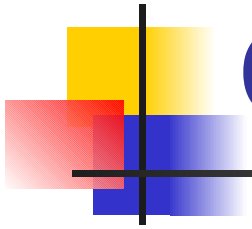
All these planning systems work with ground actions

Revival of Partial Order Planning



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

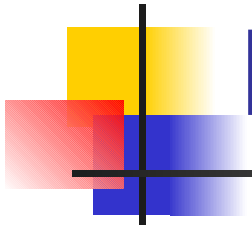
Is there some inherent power in planning with ground actions?



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!



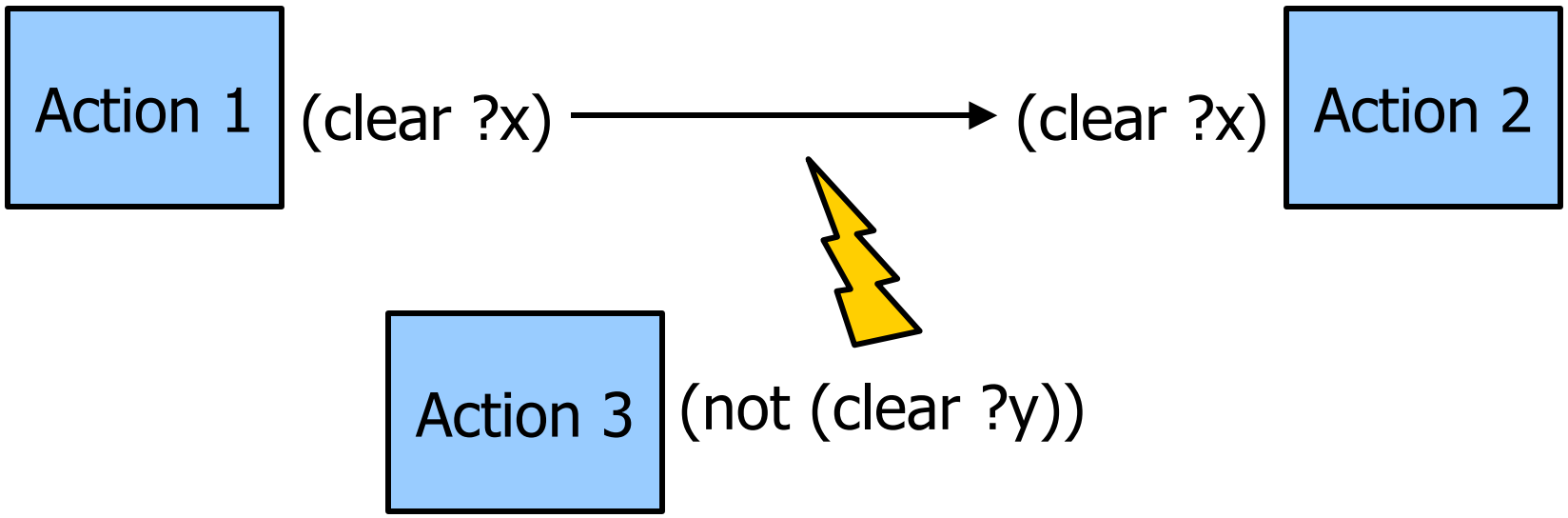
Benefits of Ground Actions

- Early commitment of parameter bindings of actions
- Enforcement of joint parameter domain constraints of actions

Early Commitment of Parameter Bindings

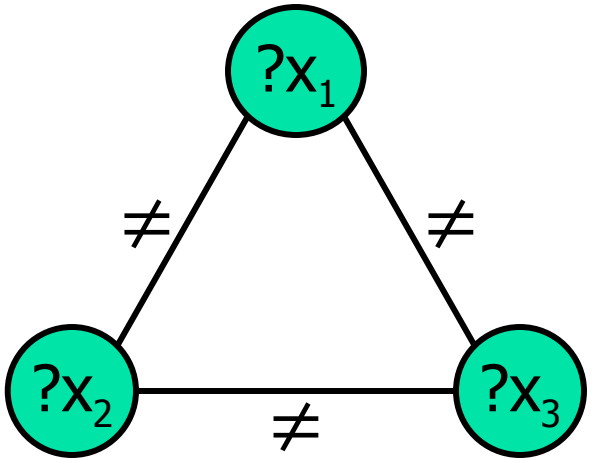
- Makes detecting inconsistencies easier

Example:



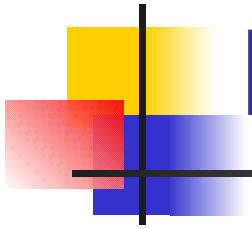
Early Commitment of Parameter Bindings

- Makes detecting inconsistencies easier



Is there a consistent assignment?

Graph coloring: Hard problem!



Benefits of Ground Actions

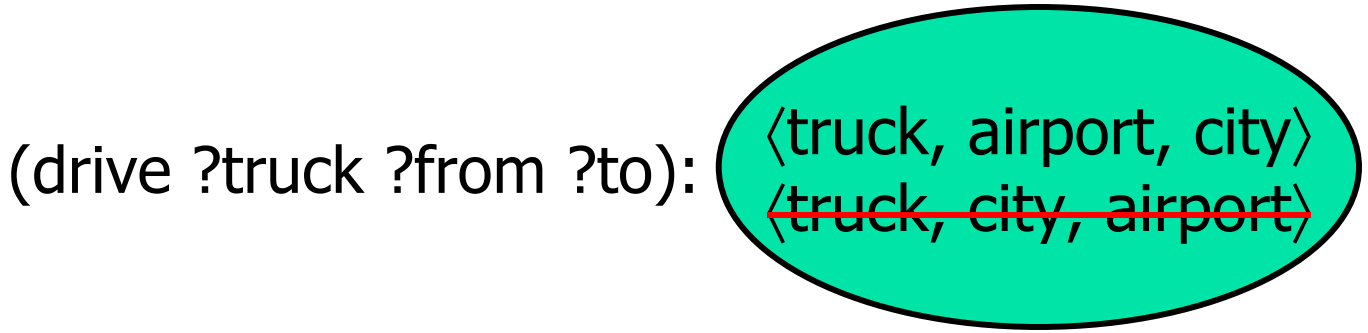
- Early commitment of parameter bindings of actions
- Enforcement of joint parameter domain constraints of actions

Joint Parameter Domain Constraints

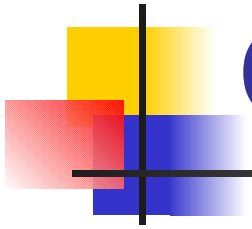
- Feasible instantiations of (drive ?truck ?from ?to):
  - (drive truck airport city)
  - (drive truck city airport)
- Joint parameter domain constraints:

(drive ?truck ?from ?to): ⟨truck, airport, city⟩ ⟨truck, city, airport⟩

Updating Joint Parameter Domain Constraints

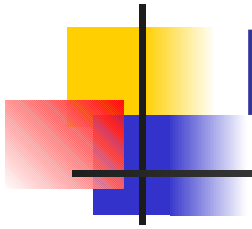


Binding constraint: ?from = airport



Contents of This Talk

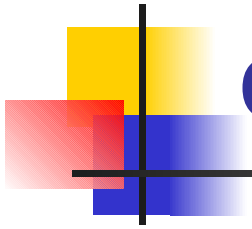
- Identify key benefits of ground actions
- Use early commitment of parameter bindings and joint parameter domain constraints to improve planning with partially instantiated actions



Partial Order Planning

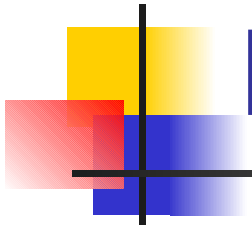
- In each iteration of POP algorithm:
  - Select a plan to expand
  - Select flaw
    - threatened causal link
    - unachieved precondition
  - Repair flaw

Implementing Early Commitment of Parameter Bindings

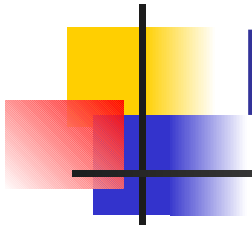


- Implement it as flaw selection strategy
  - Select static preconditions first
- Rationale:
  - Static preconditions must be linked to the initial conditions
  - The initial conditions contain no variables
  - Therefore, linking static preconditions will bind action parameters to objects

Implementing Joint Parameter Domain Constraints



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

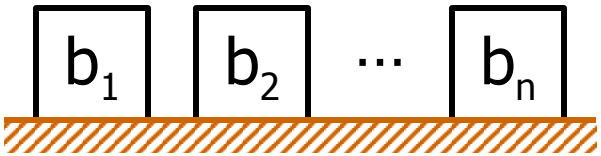


Empirical Evaluation

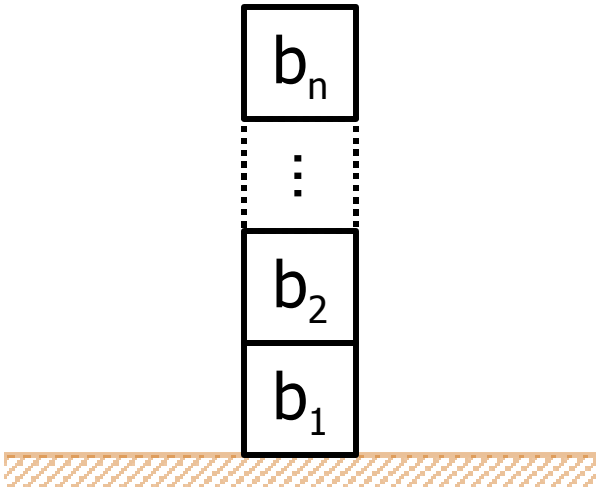
- Hypothesis:
  - Should explore about as many plans as when using ground actions
  - Should generate fewer plans

Blocks World Domain

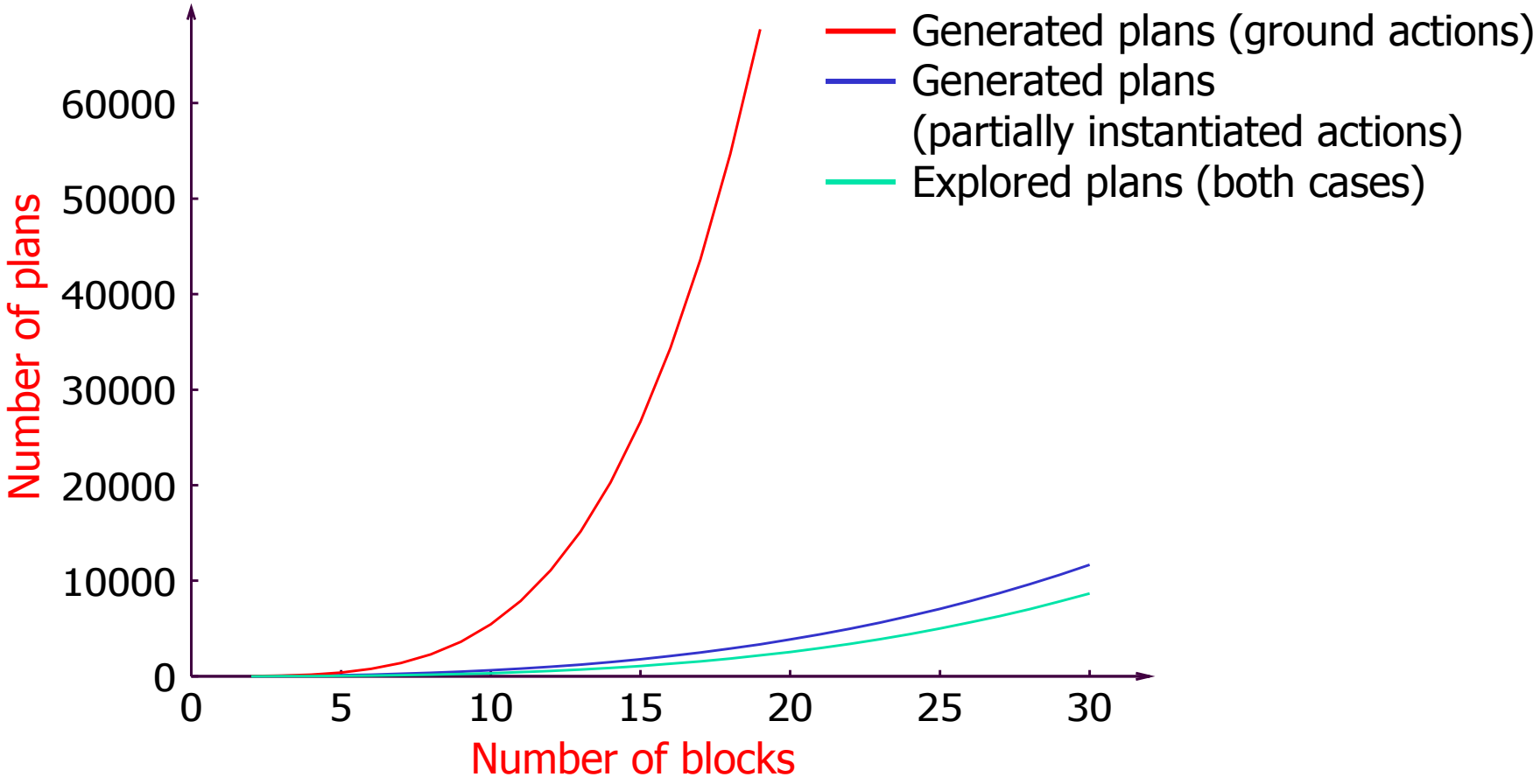
Initial state:



Goal state:

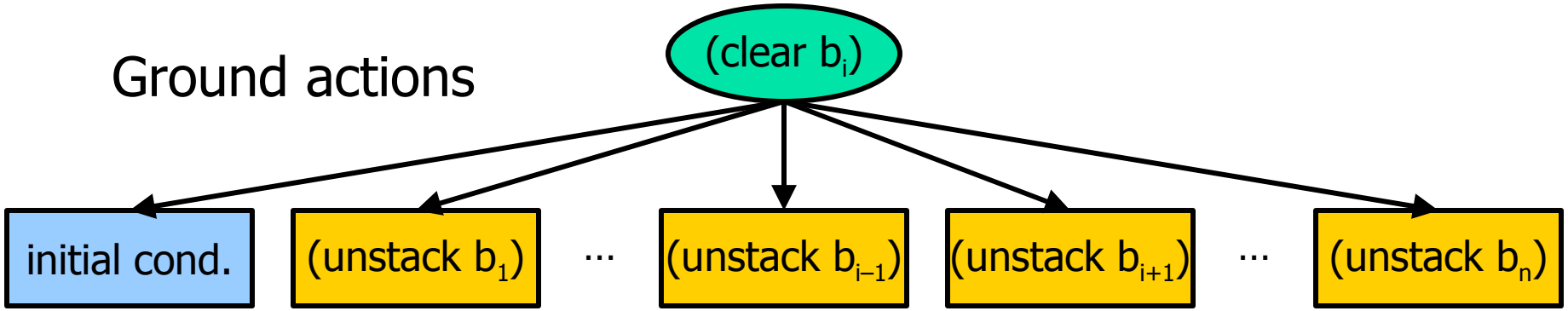


Results in Blocks World Domain

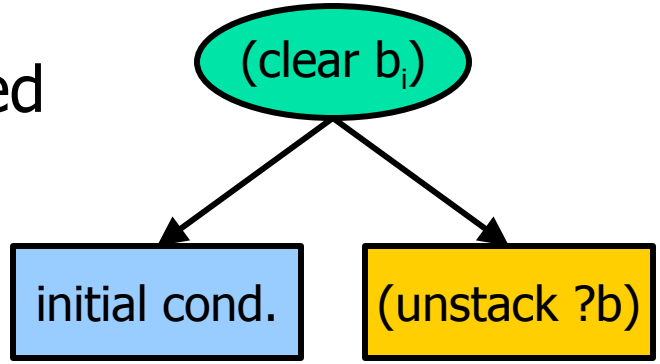


Search Tree in Blocks World Domain

Ground actions



Partially instantiated actions

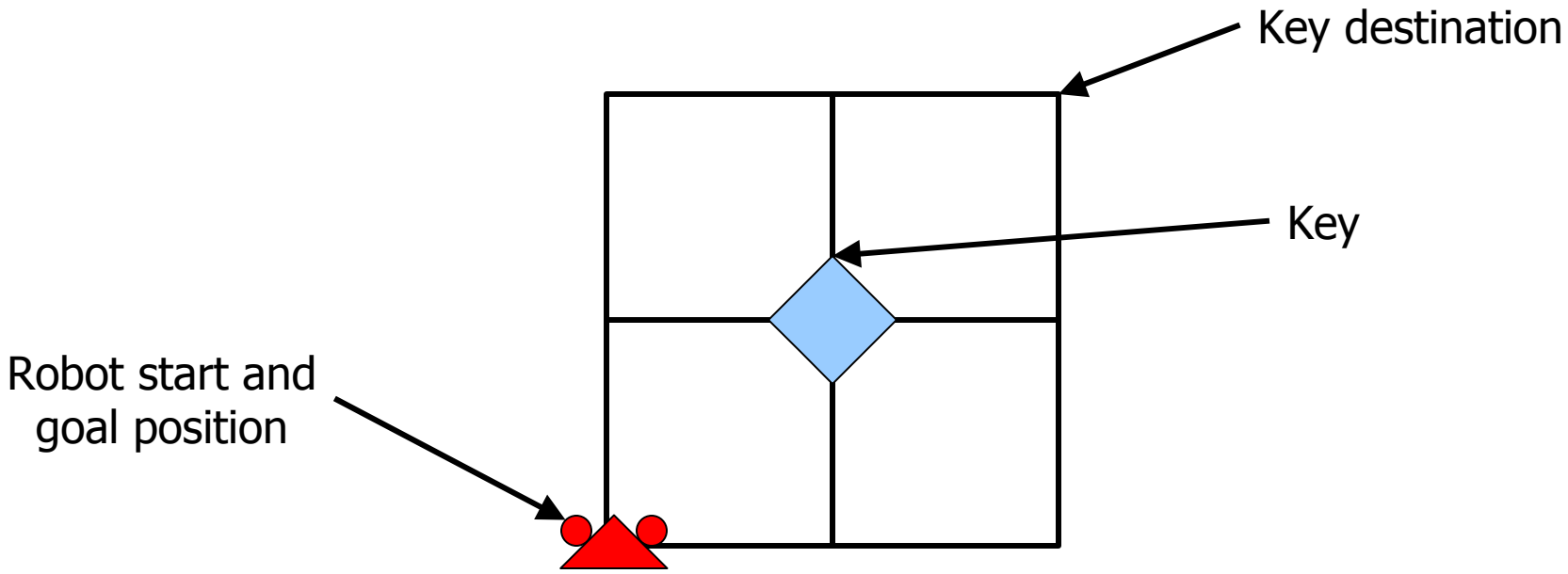


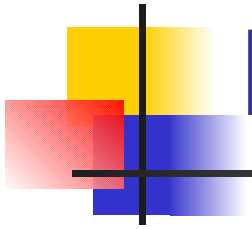
Relative Performance

- Performance partially instantiated/Performance ground

Domain	Generated plans	Explored plans	Planning time
Blocks world	0.04-0.77	1.0	0.54-1.0
Gripper	0.43-0.52	1.0	2.2-2.6
Logistics	0.80-1.0	1.0-1.2	6.7-12.0

Grid World Domain

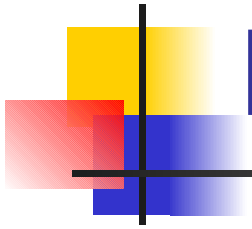




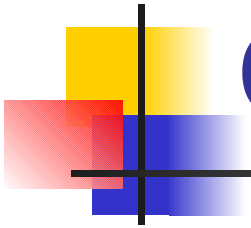
New Flaw Selection Strategy

- "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

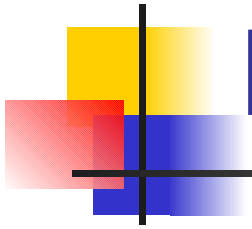


- Using LCFR and partially instantiated actions
  - Generated/explored plans: 3,704/3,084
  - Planning time: 3.76 seconds
- Using LCFR and ground actions
  - Generated/explored plans: >100,000/>60,000 (search limit reached)
  - Planning time: >19.8 seconds



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