Lifted Successor Generation using Query Optimization Techniques

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```
(:action stack
 :parameters (?x ?y)
 :precondition (and (holding ?x)
                    (clear ?y))
 :effect (and (not (holding ?x))
              (not (clear ?y))
              (clear ?x)
              (handempty)
              (on ?x ?y)))
```

```
(:objects block1, block2, ..., block100)
```

```
(:action stack
 :parameters (?x ?y)
 :precondition (and (holding ?x)
                    (clear ?y))
 :effect (and (not (holding ?x))
              (not (clear ?y))
              (clear ?x)
              (handempty)
              (on ?x ?y)))
```

```
(:objects block1, block2, ..., block100)
```

```
(stack block1 block2)
(stack block1 block3)
...
(stack block1 block100)
...
(stack block100 block99)
```

Almost 10.000 ground actions is still fine.

But grounding is not always fine.

Organic Synthesis domain, instance #11:

almost 71.000.000.000.000 ground actions.

Guess the optimal plan length.

2

Grounding is usually fine.

But sometimes it requires 35 trillion times more effort than we need.

What can we do about it?

Lifted Planning: Ground States + Action Schemas

Lifted Planning: Ground States + Action Schemas

```
(:predicates (at ?x ?y) (path ?x ?y))


(:init (at obj1 l1)
       (at obj2 l1)
       (at obj3 l3)
       (at obj4 l2)
       (path l1 l2)
       (path l1 l3)
       (path l2 l3)
       (path l3 l4))
```

at	
obj1	l1
obj2	l1
obj3	l3
obj4	l2

path	
l1	l2
l1	l3
l2	l3
l3	l4

Lifted Planning: Ground States + Action Schemas

Lifted Planning: Ground States + Action Schemas

```
(:precondition
(and (at ?X ?Y)
     (path ?Y ?W)
     (path ?W ?Z)))
```

```
(:precondition
(and (at ?X ?Y)
     (path ?Y ?W)
     (path ?W ?Z)))
```

$$at(X,Y) \bowtie path(Y,W) \bowtie path(W,Z)$$

*These are **conjunctive queries**.*

at	
X	Y
obj1	l1
obj2	l1
obj3	l3
obj4	l2

$\bowtie$

path	
Y	W
l1	l2
l1	l3
l2	l3
l3	l4

$\bowtie$

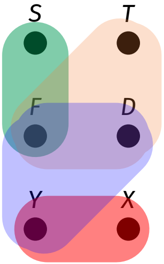
path	
W	Z
l1	l2
l1	l3
l2	l3
l3	l4

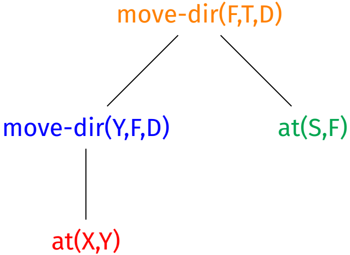
$at(X,Y) \bowtie path(Y,W) \bowtie path(W,Z)$			
X	Y	W	Z
obj1	l1	l2	l3
obj1	l1	l3	l4
obj2	l1	l2	l3
obj2	l1	l3	l4
obj4	l2	l3	l4

Conjunctive queries are NP-hard.

But there's a significant island of tractability.

- 🟥 at(X, Y)
- 🟩 at(S, F)
- 🟦 move-dir(Y, F, D)
- 🟧 move-dir(F, T, D)





Conjunctive queries with join-trees have ***acyclic hypergraphs****.*

They are solvable in output-polynomial time.

Almost 87% of the action schemas in IPC have preconditions with acyclic hypergraphs.

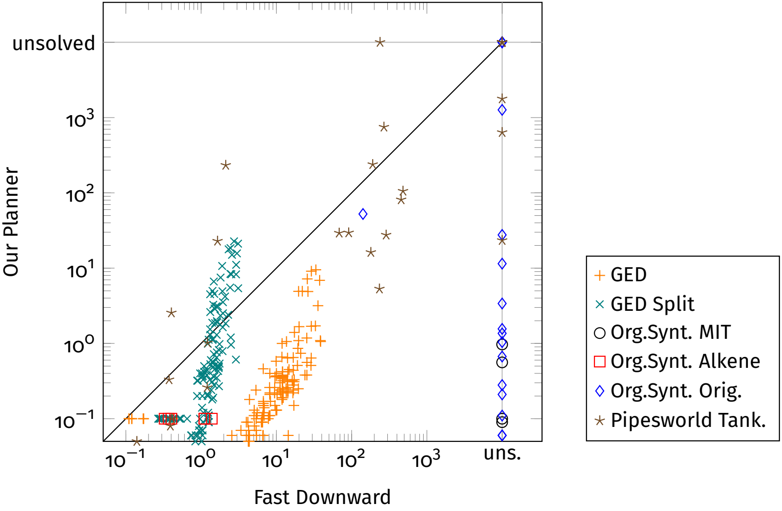
If we focus on hard-to-ground domains, then it is only 21%.

Great part of this is due to inequality constraints.

Processing inequalities:
80% in hard-to-ground domains.

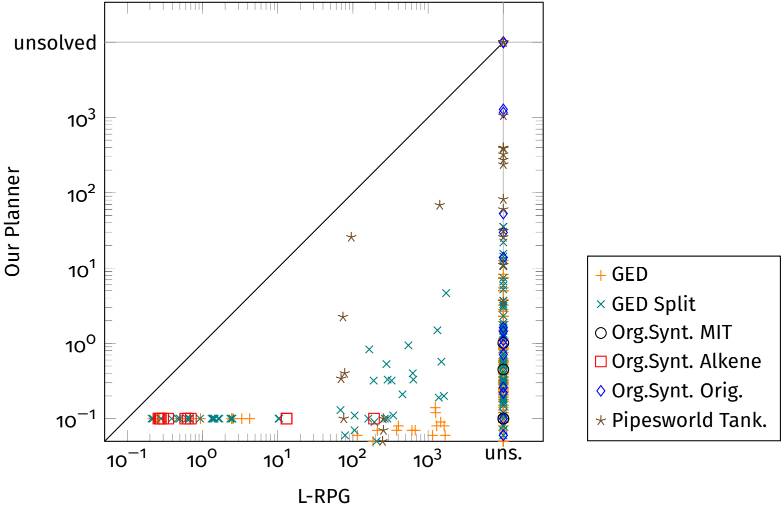
Is this good in practice?

Time (s)



unsolved
10^3
10^2
10^1
10^0
10^{-1}
Our Planner
10^{-1}
10^0
10^1
10^2
10^3
uns.
Fast Downward
+ GED
× GED Split
○ Org.Synt. MIT
□ Org.Synt. Alkene
◇ Org.Synt. Orig.
⋆ Pipesworld Tank.

Time (s)



unsolved
10^3
10^2
10^1
10^0
10^{-1}
Our Planner
10^{-1}
10^0
10^1
10^2
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⋆ Pipesworld Tank.

Conclusions

- Lifted planning can help in hard-to-ground domains.
- Most planning action schemas have acyclic preconditions.
- Much faster than previous state-of-the-art lifted planners.