Sokoban: Search in a complex domain

Yann Chazallon, Nicolas Dossou-Gbété, Tony Chan Ki Hong
and Michal Staniaszek

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What is Sokoban?

Sokoban is a puzzle game first published in 1982

- The goal is to push boxes onto goal locations in a map
- Player can move up, down, left or right
- Boxes can only be pushed into empty spaces
- Can only move one box at a time

Why is it interesting?

- AI in games—investigate techniques in simple environments
- High branching factor comparable to chess, based on possible box moves
- Solution depth much deeper than any chess game
- Solutions can be arbitrarily long due to repeated motions

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Board Representation

- Two layers
  - Static (walls, goals): singleton
  - Dynamic (player, boxes): search space
- Static cost map calculated at launch
  - Cost from each point to each goal
  - Cost from each point to each initial box position

Static Lock and Cost Map

```
###XXXXX#######
#X#XXXXX#X210X#
#X#######6321X#
#Xcba98765432X#
#########XXXXX#
XXXXXXXX#######
```

Board hashing and equality

- Hash: array of chars: `blank`, `$` and `@`
- 2 versions: with and without player position
- Used for getHash(), getHashCode(), equals()
- 3 types of equality checks used:
  - Without player position: check if state is goal
  - With top leftmost player position: repeated state checks
  - Exact player position: during the actual path reconstitution

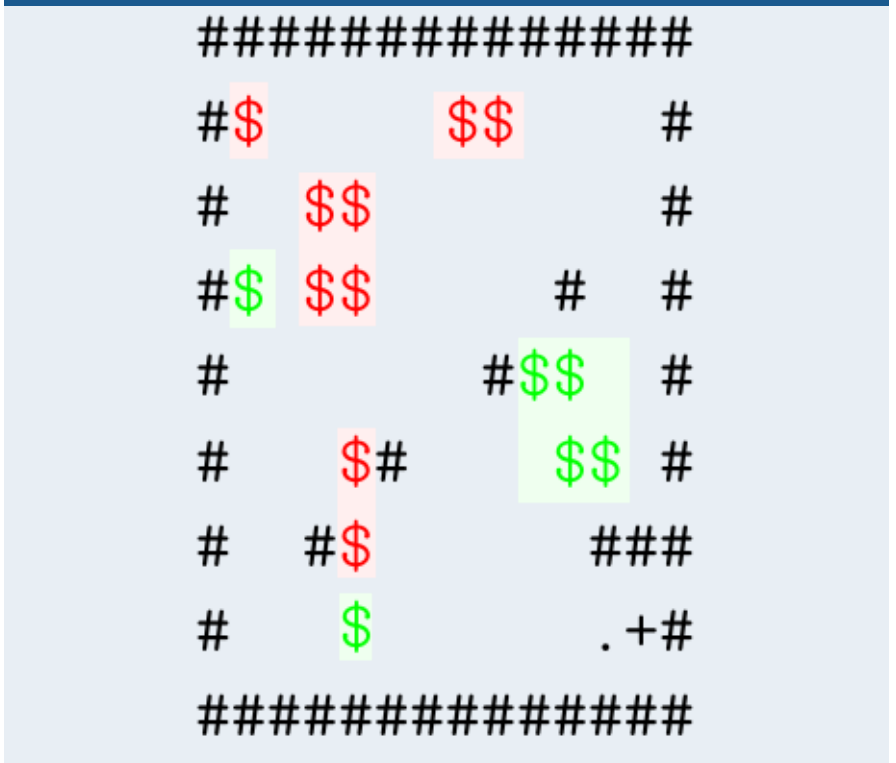
Heuristics

- First heuristic: Manhattan distances
- Other unsuccessful attempts:
  - Real cost
  - Pseudo MinMatching

Locked State Detection

- Not using any pattern dictionary
- First implementation was building a graph of dependencies
- Then improved to explore implicit graph
- Should never return false positives
- Side-effect: able to detect corner locks (redundancy with static check)

Dynamic Lock Test Map



Player Space Search

Our first approach

- Successors of states based on the motions of the player
- Very slow—useless moves, even deeper solutions
- Applied A* search to find solutions
- Only trivial maps solved

Board Space Search

Improvement on the player space search

- Successors of states based on possible moves of accessible boxes
- Search changed to best-first search—don't need to find optimal solution
- BFS is complete, since we are using a closed list
- A* used to rebuild player path when a solution is found
- Managed to solve some nontrivial maps

Bi-directional Search

Our final version, improved search method rather than heuristics

- Previous attempts at improving heuristics failed
- Improving search seemed to be a better option
- Reduces the complexity from $\mathcal{O}(b^d)$ to $\mathcal{O}(b^{d/2})$
- Need to use multiple initial states for the reverse search

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Method Comparison

Search Method	Time limit		
	5 sec	11 sec	15 sec
A*	12	15	16
Best First	56	60	64
Bi-directional Best First	76	81	82
Bi-directional A*	39	41	43

- No significant difference in number of maps solved with different limits
- Is the search going in the right direction?

Map Performance

- Can be solved within 15 sec, but not 11
- Requires a box to be positioned (at `x`) and not moved until the end.
- Problem is caused by heuristic preferring boxes on goals

Map 54

```
  ###########
  #  . . .  #
  # . . . . #
  ####### x #
  #    $ $  #
  #       # #
  ###$####   #
  #@ $   #$ #
  ### $  $  #
    ##      #
     #######
```

Map Performance

- Solved very quickly
- All but one box require only a single move
- Heuristic gives accurate estimate to the goal

Map 66

```
#########
##.$@ ###
###.# ###
###$#   #
#.$ #.# #
##.$ $# #
#.$ # # #
## #.$  #
#.$ #.###
##.$ $###
#.$ # ###
## $# ###
## .# ###
##    ###
#########
```

Map Performance

- Unsolved within 15 sec
- Intermediate goal area causes issues with heuristic
- Requires making specific move sequences to get boxes on goals

Map 93

```
##################
####    @##  #  #
###   $ ##      #
##   $ ##    ## ###
#   $ ##    ##  # #
#  $ ##    ##   $ #
# $ ##    ##  # # #
#  ##    ##  ## # #
#       ##  ### # #
####*  ##   ### # #
   #**##          #
   #######..*.#####
         ##...#
          #####
```

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Reflection and Conclusions

- Focussed more on search than heuristic
- Did not consider memory requirements—could improve map representation
- Took a long time to get a simple solver
- A* is good, but application dependent

Questions

?