SSN College of Engineering

Department of Computer Science and Engineering

CS1504 — Artificial Intelligence

2021 – 2022

Assignment — 03
(State Space Search — Decantation Problem)

August 9, 2021

Problem Statement

You are given an 8-litre jar full of water and two empty jars of 5- and 3-litre capacity. You have to get exactly 4 litres of water in one of the jars. You can completely empty a jar into another jar with space or completely fill up a jar from another jar.

1. Formulate the problem: Identify states, actions, initial state, goal state(s). Represent the state by a 3-tuple. For example, the initial state state is (8,0,0). (4,1,3) is a goal state (there may be other goal states also).
2. Use a suitable data structure to keep track of the parent of every state. Write a function to print the sequence of states and actions from the initial state to the goal state.
3. Write a function next states(s) that returns a list of successor states of a given state s.
4. Implement Depth-First-Search and Depth-Limited-Search algorithms to search the state space graph for a goal state that produces the required sequence of pouring's. Use a Queue as a frontier that stores the discovered states yet to be explored.

Responses

1. Formulated below (State Space Formulation)
2. A stack data structure is used to perform Depth-First-Search and Depth-limited search algorithms (Stack.py)

_____A dictionary with first explored parent of each state is maintained

3. Function implemented as *get_next_state(state)* (StateFunctions.py)

(*Link to **repl.it** implementation repository* **)**

State Space Formulation

3-tuple Representation

(a, b, c) where,

a is the amount of water in the 8-liter jar

b is the amount of water in the 5-liter jar

c is the amount of water in the 3-liter jar

Initial State : (8, 0, 0)

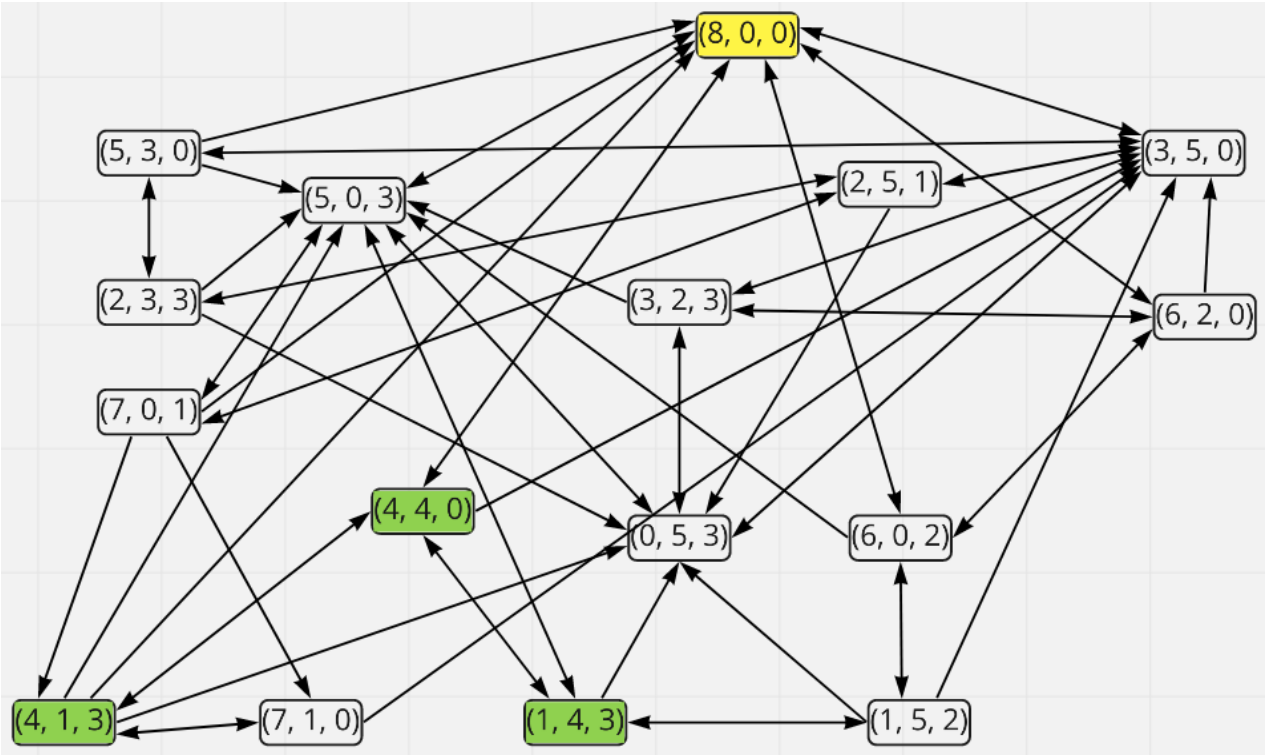
Allowed actions to progress to Next State :

1. Empty a jar into another with empty space
2. Fill up a jar completely from another jar

Constraint: Sum of quantity of water over all jars is always equal to 8 liters

Goal State : One of the three jars contains exactly 4L of water

State Transition Diagram



Python Program Code

1. Stack.py - Script for Stack ADT

```
class Stack:
   # [TOP, ..... , BOTTOM]
   def __init__(self, data_list=None):
       self.data = list()
       self.size = 0
       if data_list is not None:
           self.data.extend(data_list)
           self.size = len(data_list)

   def push(self, data_list):
       self.data = data_list + self.data
       self.size += len(data_list)

   def pop(self):
       if self.size == 0:
           return None
       self.size -= 1
       return self.data.pop(0)

   def is_empty(self):
       return self.size==0
```

2. StateFunctions.py - Functions to generate and evaluate states

```
# CONSTANTS
CAPACITY = (8,5,3)
NUM_JUGS = 3
INITIAL_STATE = (8,0,0)

def get_next_states(state):

   # Transfer water from jug 'from_' to 'to'
   def transfer(from_, to):
```

```
        # Find bottleneck
        space = CAPACITY[to] - state[to]
        water = state[from_]
        transit = min(space, water)
        # Perform transfer
        new_state = list(state)
        new_state[to] += transit
        new_state[from_] -= transit
        return tuple(new_state)

    # From i to j
    # Check all possible combinations
    result = list()
    for i in range(NUM_JUGS):
        for j in range(NUM_JUGS):
            if (i==j):
                # Self-transfer is meaningless
                continue
            if CAPACITY[j]==state[j]:
                # Cannot fill more
                # Destination full
                continue
            if state[i]==0:
                # Nothing to transfer
                # Source empty
                continue
            result.append(transfer(i,j))
    return result

def is_goal_state(state):
    return 4 in state
```

3. main.py - Driver function for DFS and DepthLimited

```
from Stack import *
from StateFunctions import *
```

```
line = "----------------------------"


def deduce_path(state, parents):

    def deduce_path_rec(state, path_seq):
        this_parent = parents[state]
        # Reached the root node
        if this_parent is None:
            return path_seq
        # Prepend node
        path_seq = [this_parent] + path_seq[:]
        return deduce_path_rec(this_parent, path_seq)

    return deduce_path_rec(state, [])


def make_path_string(path, depths):
    string_path = list()
    for state in path:
        string_path.append("{state} (Depth:
{depth})".format(state=state, depth=depths[state]))
    return string_path


def DFS():

    state_space = Stack([INITIAL_STATE])
    goal_states = list()
    explored_states = set()
    parents = {INITIAL_STATE: None}

    while not state_space.is_empty():
        # Get next state and its path
        state = state_space.pop()
        # Skip iteration if state already explored
        if state in explored_states:
            continue
```

```
        explored_states.add(state)
        # Check if the state is a goal-state
        if is_goal_state(state):
            goal_states.append(state)
        # Find the next states
        fringe = get_next_states(state)
        state_space.push(fringe)
        # Add parent of each fringe state, if not already added
        for new_state in fringe:
            if new_state not in parents:
                parents[new_state] = state

    return goal_states, explored_states, parents


def DepthLimited(limit):

    state_space = Stack([INITIAL_STATE])
    depth_track = Stack([0])
    goal_states = list()
    explored_states = set()
    parents = {INITIAL_STATE: None}
    depths = {INITIAL_STATE: 0}

    while not state_space.is_empty():
        # Get next state and its path
        state = state_space.pop()
        curr_depth = depth_track.pop()
        # Skip iteration if state already explored
        if state in explored_states:
            continue
        if curr_depth > limit:
            continue
        explored_states.add(state)
        # Check if the state is a goal-state
        if is_goal_state(state):
            goal_states.append(state)
        # Find the next states
        fringe = get_next_states(state)
```

```
        state_space.push(fringe)
        # Add parent and depth of each fringe state, if not already
added
        fringe_depths_list = list()
        for new_state in fringe:
            if new_state not in parents:
                parents[new_state] = state
                depths[new_state] = curr_depth+1
                fringe_depths_list.append(curr_depth+1)
            else:
                fringe_depths_list.append(depths[new_state])
        depth_track.push(fringe_depths_list)

    return goal_states, explored_states, parents, depths


if __name__ == '__main__':

    print(" \n"+line)
    print("DEPTH First Search")
    goal_states, explored_states, parents = DFS()

    print("\nDISTINCT EXPLORED STATES COUNT: ", len(explored_states))

    print("\nGOAL STATES COUNT: ", len(goal_states))

    print("\nINITIAL STATE")
    print(INITIAL_STATE)

    print("\nGOAL STATES")
    for state in goal_states:
        print(state)

    print("\nEXPLORED STATES")
    for state in explored_states:
        print(state)

    for state in goal_states:
        print("\nPATH to reach", state)
```

```
        print("\n".join(map(str, deduce_path(state, parents))))
        print(state, '--> GOAL STATE')


    depth_limit = 7
    print("\n"+line)
    print("DEPTH-LIMITED Search (limit: {})".format(depth_limit))
    goal_states, explored_states, parents, depths =
DepthLimited(depth_limit)

    print("\nDISTINCT EXPLORED STATES COUNT: ", len(explored_states))

    print("\nGOAL STATES COUNT: ", len(goal_states))

    print("\nINITIAL STATE")
    print(INITIAL_STATE)

    print("\nGOAL STATES")
    for state in goal_states:
        print(state)

    print("\nEXPLORED STATES")
    for state in explored_states:
        print(state)

    for state in goal_states:
        print("\nPATH to reach", state)
        print("\n".join(make_path_string(deduce_path(state, parents),
depths)))
        print(state, '--> GOAL STATE')
```

(Output on next page)

Sample Output (depth-limit = 7 for Depth Limited Search)

```
DEPTH First Search

DISTINCT EXPLORED STATES COUNT:  16

GOAL STATES COUNT:  3

INITIAL STATE
(8, 0, 0)

GOAL STATES
(4, 1, 3)
(4, 4, 0)
(1, 4, 3)

EXPLORED STATES
(6, 2, 0)
(2, 3, 3)
(3, 2, 3)
(0, 5, 3)
(3, 5, 0)
(7, 0, 1)
(2, 5, 1)
(7, 1, 0)
(1, 4, 3)
(6, 0, 2)
(1, 5, 2)
(4, 1, 3)
(5, 0, 3)
(4, 4, 0)
(5, 3, 0)
(8, 0, 0)

PATH to reach (4, 1, 3)
(8, 0, 0)
(5, 0, 3)
(5, 3, 0)
(2, 3, 3)
(2, 5, 1)
(7, 0, 1)
(7, 1, 0)
(4, 1, 3) --> GOAL STATE
```

```
PATH to reach (4, 4, 0)
(8, 0, 0)
(5, 0, 3)
(5, 3, 0)
(2, 3, 3)
(2, 5, 1)
(7, 0, 1)
(7, 1, 0)
(4, 1, 3)
(4, 4, 0) --> GOAL STATE

PATH to reach (1, 4, 3)
(8, 0, 0)
(5, 0, 3)
(5, 3, 0)
(2, 3, 3)
(2, 5, 1)
(7, 0, 1)
(7, 1, 0)
(4, 1, 3)
(4, 4, 0)
(1, 4, 3) --> GOAL STATE

----------------------------
DEPTH-LIMITED Search (limit: 7)

DISTINCT EXPLORED STATES COUNT:  15

GOAL STATES COUNT:  2

INITIAL STATE
(8, 0, 0)

GOAL STATES
(4, 1, 3)
(1, 4, 3)
```

```
EXPLORED STATES
(6, 2, 0)
(2, 3, 3)
(3, 2, 3)
(0, 5, 3)
(3, 5, 0)
(7, 0, 1)
(2, 5, 1)
(7, 1, 0)
(6, 0, 2)
(1, 4, 3)
(4, 1, 3)
(5, 0, 3)
(1, 5, 2)
(5, 3, 0)
(8, 0, 0)

PATH to reach (4, 1, 3)
(8, 0, 0) (Depth: 0)
(5, 0, 3) (Depth: 1)
(5, 3, 0) (Depth: 2)
(2, 3, 3) (Depth: 3)
(2, 5, 1) (Depth: 4)
(7, 0, 1) (Depth: 5)
(7, 1, 0) (Depth: 6)
(4, 1, 3) --> GOAL STATE

PATH to reach (1, 4, 3)
(8, 0, 0) (Depth: 0)
(3, 5, 0) (Depth: 1)
(3, 2, 3) (Depth: 2)
(6, 2, 0) (Depth: 3)
(6, 0, 2) (Depth: 4)
(1, 5, 2) (Depth: 5)
(1, 4, 3) --> GOAL STATE
```