Application of DFS, BFS, and UCS for Sokoban Game

Quan Hoang Ngoc - 22521178

3/2024

In this project, we install search algorithms such as DFS, BFS, and UCS to apply them to solve the Sokoban game by modeling them as a search problem. We also conduct experiments and statistics to compare algorithms as well as evaluate the difficulty of the game.

A. Application of DFS, BFS, and UCS for Sokoban Game

- To understand the application of search algorithms (DFS, BFS, and UCS) for the Sokoban Game, we need to understand the structure of programs.
- Whenever the function **game.py/Game/auto_move** (or the users click 'auto move' mode) then the function **solver.py/get_move** will be activated and call one of three algorithms including **DFS, BFS and UCS** to search for a solution which leads to a goal state *to win the game*.

B. Modeling Sokoban Game

- Solving a Sokoban task can be modeled as a **search problem** in which we need to find a solution (path = sequence of actions including 'up', 'down', 'left', 'right') so that from initialize the state of the game we can go to the end-state that wins the game.
- Thus, we can model the Sokoban World by some concepts such as:
    - **State**: information about the position of the player and the position of the boxes.
    - **Start state**: the state when we perform one of three functions (DFS, BFS, UCS). Typically, it is when we start a level of game.
    - **End state**: the state where we win the game (all boxes are in the correct position).
    - **State Space**: all states that can be reached from the start state. It is the totality of possible positions of the player and boxes. It is frequently represented as a graph.
    - **Action**: 'up', 'down', 'left', 'right' correspond to moving the player up, down, left, and right.
    - **Legal Action**: an action is called 'Legal' if it makes the function **solver.py/isLegalAction** true. In other words, it does not cause the player to move into walls or boxes. Besides, in algorithms, an action only be considered if it is not *Failed.* It does not cause a box that is not in the correct position but it can not move anymore.
    - **Successor function**: A successor function describes the agent's options: given a state, it returns a set of (action, next state) pairs. It indicates actions and states corresponding to an input state. In this setting code, it is a combination of function **solver.py/legalAction** (Return all legal actions for the agent in the current game state) and function **solver.py/updateState** (Return updated game state after an action is taken).

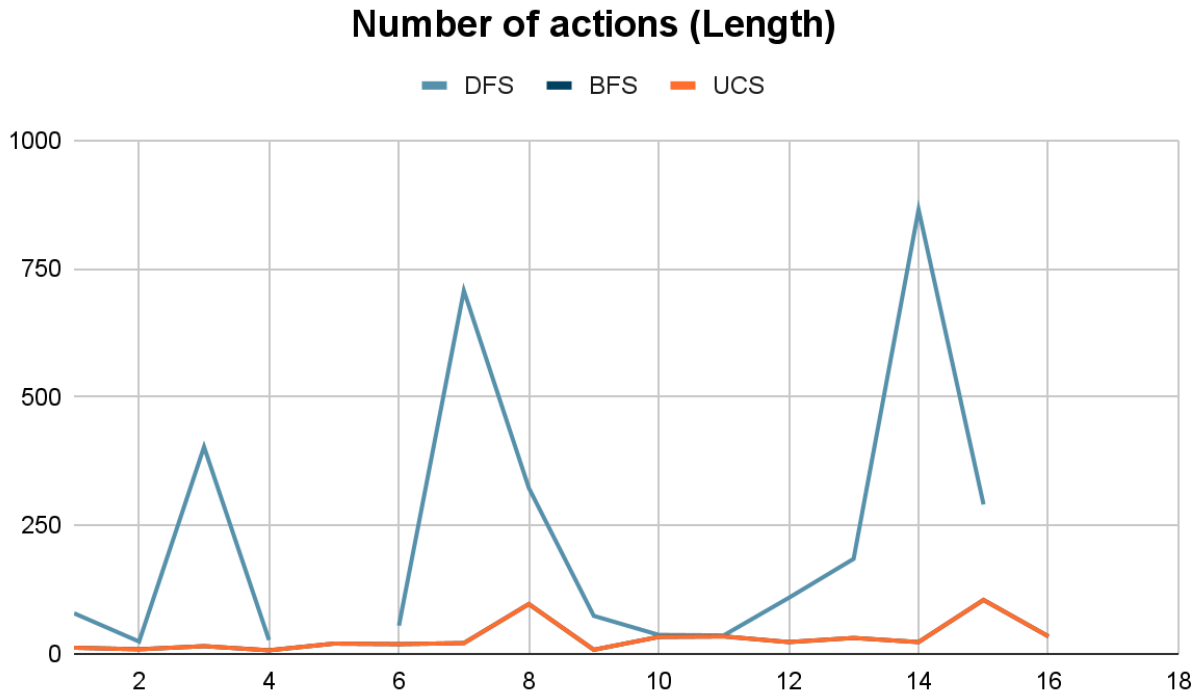
C. Statistics and Evaluation

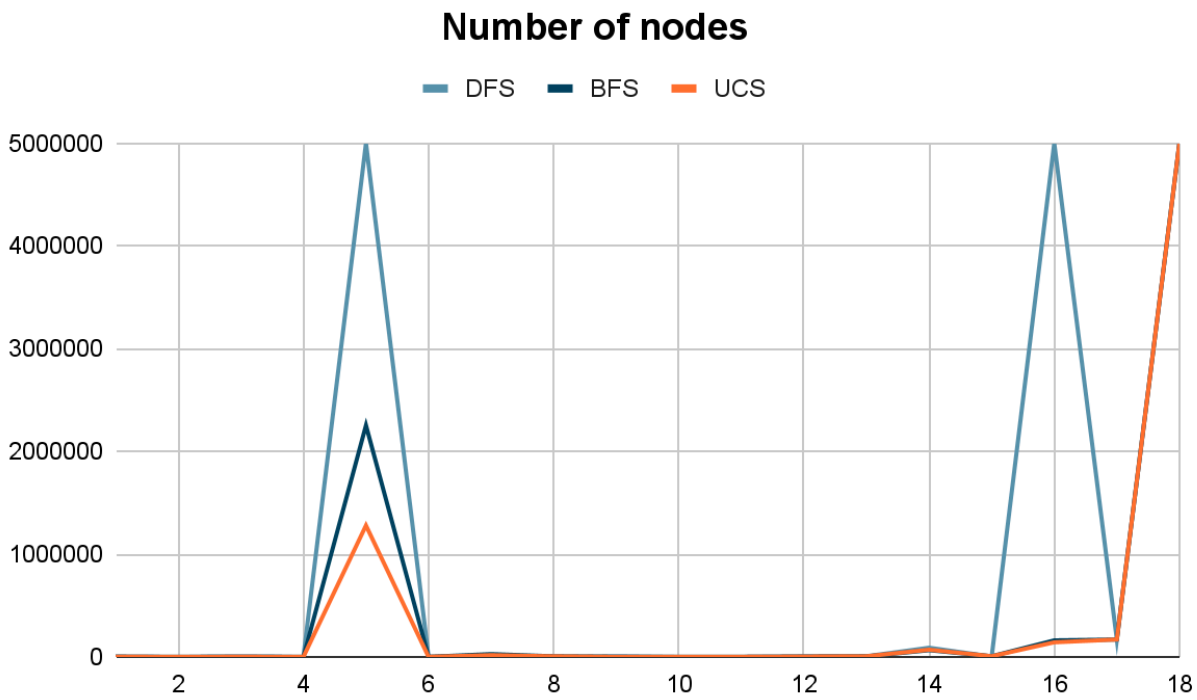
- Let's evaluate the performance of algorithms, we need to measure some quantity such as: the length of solution (number of actions that need to be performed) - **L**, and the number of nodes (state) that can be processed by algorithm - **N**.

Statistics Algorithms Table-[1]

	DFS		BFS		UCS	
Level	**L**	**N**	**L**	**N**	**L**	**N**
1	79	2177	12	2552	12	1634
2	24	55	9	186	9	181
3	403	4582	15	2137	15	1218
4	27	41	7	230	7	171
5		OOM	20	2253288	20	1278998
6	55	524	19	612	19	595
7	707	16221	21	27307	21	16767
8	323	1756	97	5561	97	5356
9	74	7142	8	141	8	174
10	37	392	33	509	33	524
11	36	638	34	671	34	657
12	109	5116	23	2959	23	2966
13	185	6341	31	4905	31	6011
14	865	88800	23	65221	23	69842
15	291	3842	105	6362	105	6325
16		OOM	34	160839	34	141814
17	x	169158	x	169158	x	169158
18		OOM		OOM		OOM

Notion:
[x]: not find a solution
[OOM]: Out of Memory
The computer used for statistics is **Kaggle Colab P100: 29GB RAM**.





1. Evaluate Length (number of actions)

- In these maps of the Sokoban Game, both BFS and UCS find the shortest path (minimum number of actions) if there is a solution. But typically, UCS will search for the solution in a shorter time, because it processes fewer nodes.

- DFS does not find a shortest path, the path can be very long. But, in some maps that have many solutions to win and the length of the solution is not deep, it can be effective.

2. Evaluate Performance of Algorithms

- We expect an algorithm to find the exact solution (shortest path) and the execution time is minimal. The accuracy of the solution is expressed by the length of the solution and the execution time is expressed by the number of nodes that can be processed by the algorithm.
- We define a quantity as the goodness of the algorithm as follows: G = L + 2N
- Because we expect to find the solution faster, the weight of N will be larger than L.
- But L and N are two different quantities (they are not in the same range) so we need to normalize them:
    - L = (L - 7)/(865 - 7)
    - N = (N - 41)/(2253288 - 41)
    - If it is OOM, G = 3.

Comparison Table-[2]

	DFS	BFS	UCS	
1	0.085812015	0.008056289	0.005791188	**0.099659492**
2	0.019825946	0.002459705	0.002455267	**0.024740919**
3	0.465569089	0.011184436	0.010368724	**0.487122249**
4	0.023310023	0.000167758	0.000115389	**0.02359317**
5	3	2.015151515	1.150363944	**6.165515459**
6	0.056372771	0.014492838	0.014477749	**0.085343358**
7	0.830212313	0.040518535	0.031163147	**0.901893995**
8	0.369820616	0.109794701	0.109612741	**0.589228058**
9	0.084391482	0.001254262	0.001283553	**0.086929297**
10	3	0.030718431	0.030731745	**3.061450176**
11	0.034329436	0.032027724	0.032015298	**0.098372458**
12	0.123385729	0.021238059	0.021244272	**0.16586806**
13	0.213051138	0.032289353	0.033271048	**0.278611538**
14	1.078783196	0.076502306	0.080603943	**1.235889445**
15	3	0.119829684	0.119796843	**3.239626527**
16	3	0.174194118	0.157307376	**3.331501495**
17	1.150109597	1.150109597	1.150109597	**3.450328792**
18	3	3	3	**9**
	19.53497335	**6.839989313**	**5.950711825**	

- If G is larger, it shows that the algorithm is not good, so the best algorithm is the algorithm with the smallest total G. In other words, UCS is the best algorithm in these cases.

3. Evaluate Game Difficulty

- The map that is most difficult for a computer to solve will be the one that takes the longest to solve.
- The larger the number of nodes an algorithm needs to process, the longer it will take to run the algorithm.
- So, following Figure 2, level 18 is the most difficult. It causes all 3 algorithms to suffer Out of Memory (29 GB).
- But, if we ignore the OOM case, maybe level 5 is the most difficult.

D. Conclusion & Discussion

- We can model Sokoban World by a search problem and apply algorithms such as DFS, BFS, and UCS to search for a solution (a path) that can win the game.
- In these cases, UCS appears to be the better algorithm.
- There are many different ways to define the difficulty of the game, but if measured in terms of time, it seems that levels 18 and 5 are the most difficult.
- In the source code of this project, we use Python Programming Language to implement the algorithms, but the run time of programs is too long and slow (up hours). Instead, you can use C++ as the backend of algorithms. It will significantly improve the speed of algorithms based on data structure and control structure, thus reducing the time and resources needed to experiment.

E. References

- All about source code, experiment process documentation, and Youtube demo (if there) in this Github link: https://github.com/QuanHoangNgoc/Application_DFS_BFS_UCS_for_Sokoban_Game
- Youtube Demo Publishcation (Please Like and Subscribe)
- Author: Quan Hoang Ngoc - 22521178. Thank you.