3 Credit Group

Member: Haowen Jiang, Haojia Yu, Xiang Xiang

netID: haowenj2, xiangx2, hyu59

CS440/ECE448 Assignment1: Search

Contribution:

coding: Haowen Jiang, Xiang Xiang, Haojia Yu

report: Haowen Jiang, Xiang Xiang

Part 1 (For everyone): Pac-Man

1. Basic pathfinding

The purpose of this section is to implement four methods to find the single target. For BFS and DFS, the state is composed by the coordinate of the current point. For Greedy Best First Search and A* Search, the Manhattan distance is used to be the heuristic function. According to the essences, DFS and GBFS will not find the shortest way. Stack is implemented in DFS and queue in BFS. For GBFS and A*, the priority queue is much helpful.

Depth First Search

To implement DFS, programmer should expand the visited points and choose one of the neighbors as the next step randomly. When all of neighbors the current points is in closelist (wall or visited point just now), current point should return back to the last one. Since DFS is not a way organized by heuristic function, a little bit more step should be spent.

OpenMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     %P............%
%                     %.............%
%                     %.............%
%                     %.............%
%                     %.............%
%                     %%%%%%%%......%
%                            %......%
%                            %......%
%                            %......%
%                            %......%
%........................    %......%
%......%%%%%%%%%%%%%%%%%............%
%......%                            %
%......%                            %
%......%                            %
%......%                            %
%......%%%%                         %
%.........%                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of DFS is 628 and the steps to find the target is 181.

MediumMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%P..  %...    %.............%         %...  %...        %   %
%%%.%%%.%.%%%%%.%%%%% %%%%%.%%% %%%%%%%.%.%%%.%.%%%%%%% % %%%
%...%... .....%...% %   % %...%.........%...%.%.....% % %   %
%.%%%.%%% %%%.%%%.% %%% % %%%.%.%%%%%% %%%%.%.%%%%%.% % %%% %
%.%...% %   %.%...%   % %  ... .......    %.%...% %.%       %
%...%%% % % %.%.% % % % %%%.% %%%%%%%.%%% %.%%%.% %.%%%%%%% %
% %   %   % %...%   % %   %.%     %  .%   %.....% %...%...% %
% %%%%%%% % % %%% %%% %%% %.%%% %%% %.% %%%%%%%%% %%%.%.%.% %
%   %   % %       % % %   %...% %   %.% %.....%     %...%.% %
% % %%% % %%% %%%%% % % %%%%%.% % %%%.% %.%%%.%%%%% %%%%%.%%%
% %   % %   %         % %   %.%     %...%.% %...        %...%
% %%%%% %%%%% %%%%% %%% % % %.%%%%%%%%%.%.% %%%.%%% %%% %%%.%
%     %       %         % % %.........%...% ....%     %   %.%
% %%% %%% %%%%% %%%%% % %%% %%% %%%%%.%%%%%%.%%%% %%% %%% %.%
%   %     %     %   % %         % % %...%.... %   %     % %.%
% % %%% %%% %%% %%% % %%% %%%% %% % %%%.%.%%% % %%% %%% %%%.%
% %   %   %       %       %       %   %...% % % %     %   %.%
% % %%% % %%%% %% %%%%%%%%% %%%%% %%% % %%% % % % % %%%%% %.%
% %     %   %     %       %   %       %     %   % % %   % %.%
% %%%% %% % % %%%%% %%%%% %%% % %%%% %% %%% %% %% %%% % % %.%
%         % %           %     %           %           % %  .%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of DFS is 285 and the steps to find the target is 204.

BigMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %.........  %.......................%   %.....%.......%...%...........    %...%
% %.%%% %%%.%%%.%% %%%%%%%%%% %%%%%%%.%%% %.%%%.%.% %%%.%.%.%.%%%%% %%%.%%%%%.% %
%...%     %...%.%   %.......%   %...%...% %.%...%.% %  ...%.%.    % % %.%.....% %
%.%%%%    %%%.%.%%% %.% %%%.%%% %.%.%%%.% %.%.%%%.% %%%%% %.%.    % % %.%.%%%%% %
%...      %...%...%...% % %.%   %.%.....  %. ...%.      % %.%.%   % %...%.%     %
%%%.%% %% %.%%%%%.%.%%% % %.%  %%.% %%%% %%.%%%.%.%%%%% % %.%.% %%% %.%%%.% %%% %
%...    % %.%...%.%.% % %  .%.....% %.......% %...%   %   %...  %   %.%...% % % %
%.%%%%%%% %.%.%.%.%.% % %%%.%.%%%%% %.%%%%%%% %%%%%%% %%%%%%% %%% %%%.%.%%% % % %
%.....%   %...%...%.% %   %...%.......    %     %   %   %         %  .%...% % % %
%%%%%.% %%%%%   %%%.% %%% % %%%.%%%     % % %%% % % %%% % %%%%%%% %%%.%%%.% % % %
%.....    %     %...% %   % %...%   %   %   %     %     %   %...% %...  %.% %   %
%.%%%%%%% % %%%%%.%%% % %%% %.%%%%%%% %%%%%%%%%%% %%% %%% % %.%.%%%.% %%%.% % %%%
%...    % %    ...    % %   %.        %         % %...%   % %.%.%...% ....% %   %
%%%.% %%% %%%%%.%%%%%%% %%% %.   %% %%% %%%%% % %%%.%.%.......%.%.%%%%.%%%% %%% %
%...%   %     %.  %...%      .%         %....   %...%...% %   %...    ..  % %   %
%.% %%% %%%%% %.%%%.%.%%%%% %.% %%%%%%%%%.%%.%%%%.% %%%%% %% %%%%%%%%%%.%%% % %%%
%.%         % %.%...%.%...% %.%       %  .% ......% %...% ........%.....%   % % %
%.% %%% %%%%% %.%.%%%.%.%.%%%.%%%%%%% %%%.% %%% % %%%.%.%%.%%%%... .   %% %%% % %
%.  %   %   % %...  %.%. ...%...        %.%   % % %...%.... %...  %.    %   % % %
%.% %%%%% % % % %%% %.%.%%%.%%%.% %%    %.%%%%% %%%.%%% %%% %.%%%%%.%%% %%% % % %
%.%       % % %   % %...% %.....% %     %.....%    .      % %.......% %   % %   %
%.%%% % %%% % %%% % %  %% %%% %%% % %% %%%% %.%%%%%.%     % %   %% %% %%% % %%% %
%.%   % % %   % % %     %   %     % %       %.....%.%     %   % %     %   %     %
%.  % % % %   % % %     % % % %%% % % %%%%% %%%%%.%.% %%%%% % % % %%% % %%% % %%%
%...% %     %     %     % %   %   % % %     %.....%.% %     %   %       %   % % %
%%%.%%%% %% % %  %% %% %% % %%% % % % % %%% %.%%%%%.% % %%%%% %   % % %%% % % % %
%...%     % % %   % %   %   % % % % % %   % %.% ....% %   %   %     %   % %     %
%.  % %%% % %%% % % % % % %%% % % % % %%% %%%.%%.%%%% % % % % % %%%%% % %%% %%% %
%P      %       % % % %     %   %   %   %    ....     % %   %         %     %   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of DFS is 898 and the steps to find the target is 476.

Breadth First Search

The way to implement BFS is to iterate all the neighbors first then the second level. Obviously, queue should be helpful for BFS to find the shortest path. Meanwhile, BFS is not a heuristic function so much more steps should be spend compare to A*.

OpenMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     %P            %
%                     %.            %
%                     %.            %
%                     %.            %
%                     %........     %
%                     %%%%%%%%.     %
%                            %.     %
%                            %.     %
%                            %.     %
%                            %.     %
%     .......................%.     %
%     .%%%%%%%%%%%%%%%%%    ...     %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%%%%                         %
%     ....%                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of BFS is 1034 and the steps to find the target is 53.

MediumMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%P..  %       %             %         %     %           %   %
%%%.%%% % %%%%% %%%%% %%%%% %%% %%%%%%% % %%% % %%%%%%% % %%%
%...%.....    %   % %   % %   %         %   % %     % % %   %
%.%%%.%%%.%%% %%% % %%% % %%% % %%%%%% %%%% % %%%%% % % %%% %
%.%...% %...% %   %   % %                 % %   % % %       %
%...%%% % %.% % % % % % %%% % %%%%%%% %%% % %%% % % %%%%%%% %
% %   %   %.%   %   % %   % %     %   %   %     % %   %   % %
% %%%%%%% %.% %%% %%% %%% % %%% %%% % % %%%%%%%%% %%% % % % %
%   %   % %...    % % %   %   % %   % % %     %     %   % % %
% % %%% % %%%.%%%%% % % %%%%% % % %%% % % %%% %%%%% %%%%% %%%
% %   % %   %.......  % %   % %     %   % % %           %   %
% %%%%% %%%%% %%%%%.%%% % % % %%%%%%%%% % % %%% %%% %%% %%% %
%     %       %    .....% % %         %   %     %     %   % %
% %%% %%% %%%%% %%%%% %.%%% %%% %%%%% %%%%%% %%%% %%% %%% % %
%   %     %     %   % %........ % % %   %     %   %.....% % %
% % %%% %%% %%% %%% % %%% %%%%.%% % %%% % %%% % %%%.%%%.%%% %
% %   %   %       %       %   ....%   %   % % % %...  %...% %
% % %%% % %%%% %% %%%%%%%%% %%%%%.%%% % %%% % % %.% %%%%%.% %
% %     %   %     %       %   %  .... %.....%   %.% %   %.% %
% %%%% %% % % %%%%% %%%%% %%% % %%%%.%%.%%%.%% %%.%%% % %.% %
%         % %           %     %     ....  %.......    % %...%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of BFS is 653 and the steps to find the target is 104.

BigMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% %           %                       %   %     %       %   %               %...%
% % %%% %%% %%% %% %%%%%%%%%% %%%%%%% %%% % %%% % % %%% % % % %%%%% %%% %%%%%.% %
%   %     %   % %   %       %   %   %   % % %   % % %     % %     % % % %.....% %
% %%%%    %%% % %%% % % %%% %%% % % %%% % % % %%% % %%%%% % %     % % % %.%%%%% %
%         %   %   %   % % % %   % %       %     %       % % % %   % %   %.%     %
%%% %% %% % %%%%% % %%% % % %  %% % %%%% %% %%% % %%%%% % % % % %%% % %%%.% %%% %
%       % % %   % % % % %   %     % %       % %   %   %   %     %   % %...% % % %
% %%%%%%% % % % % % % % %%% % %%%%% % %%%%%%% %%%%%%% %%%%%%% %%% %%% %.%%% % % %
%     %   %   %   % % %   %   %           %     %   %   %         %   %...% % % %
%%%%% % %%%%%   %%% % %%% % %%% %%%     % % %%% % % %%% % %%%%%%% %%% %%%.% % % %
%         %     %   % %   % %   %   %   %   %     %     %   %   % %     %.% %   %
% %%%%%%% % %%%%% %%% % %%% % %%%%%%% %%%%%%%%%%% %%% %%% % % % %%% % %%%.% % %%%
%       % %           % %   %         %         % %   %   % % % %   % ....% %   %
%%% % %%% %%%%% %%%%%%% %%% %    %% %%% %%%%% % %%% % %       % % %%%%.%%%% %%% %
%   %   %     %   %   %       %         %....   %   %   % %   %       ..  % %   %
% % %%% %%%%% % %%% % %%%%% % % %%%%%%%%%.%%.%%%% % %%%%% %% %%%%%%%%%%.%%% % %%%
% %         % % %   % %   % % %       %  .% ....  % %   % ......  %   ..%   % % %
% % %%% %%%%% % % %%% % % %%% %%%%%%% %%%.% %%%.% %%% % %%.%%%%........%% %%% % %
%   %   %   % %.....% %.....%  ......   %.%   %.% %   %....  %     %     %   % % %
% % %%%%% % % %.%%%.% %.%%%.%%%.% %%.   %.%%%%%.%%% %%%.%%% % %%%%% %%% %%% % % %
% %       % % %...%.% ..% %.....% % ... %...  %.........  % %       % %   % %   %
% %%% % %%% % %%%.%.% .%% %%% %%% % %%.%%%%.% %%%%% %     % %   %% %% %%% % %%% %
% %   % % %   % %.%.... %   %     % % ......%     % %     %   % %     %   %     %
%   % % % %...% %.%     % % % %%% % % %%%%% %%%%% % % %%%%% % % % %%% % %%% % %%%
%   % % ....%.....%     % %   %   % % %     %     % % %     %   %       %   % % %
%%% %%%%.%% % %  %% %% %% % %%% % % % % %%% % %%%%% % % %%%%% %   % % %%% % % % %
%   %.... % % %   % %   %   % % % % % %   % % %     % %   %   %     %   % %     %
%   %.%%% % %%% % % % % % %%% % % % % %%% %%% %% %%%% % % % % % %%%%% % %%% %%% %
%P....  %       % % % %     %   %   %   %             % %   %         %     %   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of BFS is 1398 and the steps to find the target is 156.

Greedy Best-First Search

Greedy Best First Search is a kind of search that explores a graph via expanding the most promising node chosen according to the heuristic function. By setting up the heuristic function, for each step, we select the node with the best heuristic function value to expand. In our case here, we set the Manhattan Distance as the heuristic function. We always select the node with the minimal Manhattan Distance as the next node to expand. But since the real-time minimal Manhattan Distance is not always the total minimal value, while instead, usually it's only a local minimal value, due to GBFS's judgement. In our implementation, applying GBFS to openmaze get an accurate cost value, mediummaze get a relatively precise value, while for bigmaze, the error is kind of increased.

OpenMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     %P            %
%                     %.            %
%                     %.            %
%                     %.            %
%                     %........     %
%                     %%%%%%%%.     %
%                            %.     %
%                            %.     %
%                            %.     %
%                            %.     %
%     ...................    %.     %
%     .%%%%%%%%%%%%%%%%%.......     %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%%%%                         %
%     ....%                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

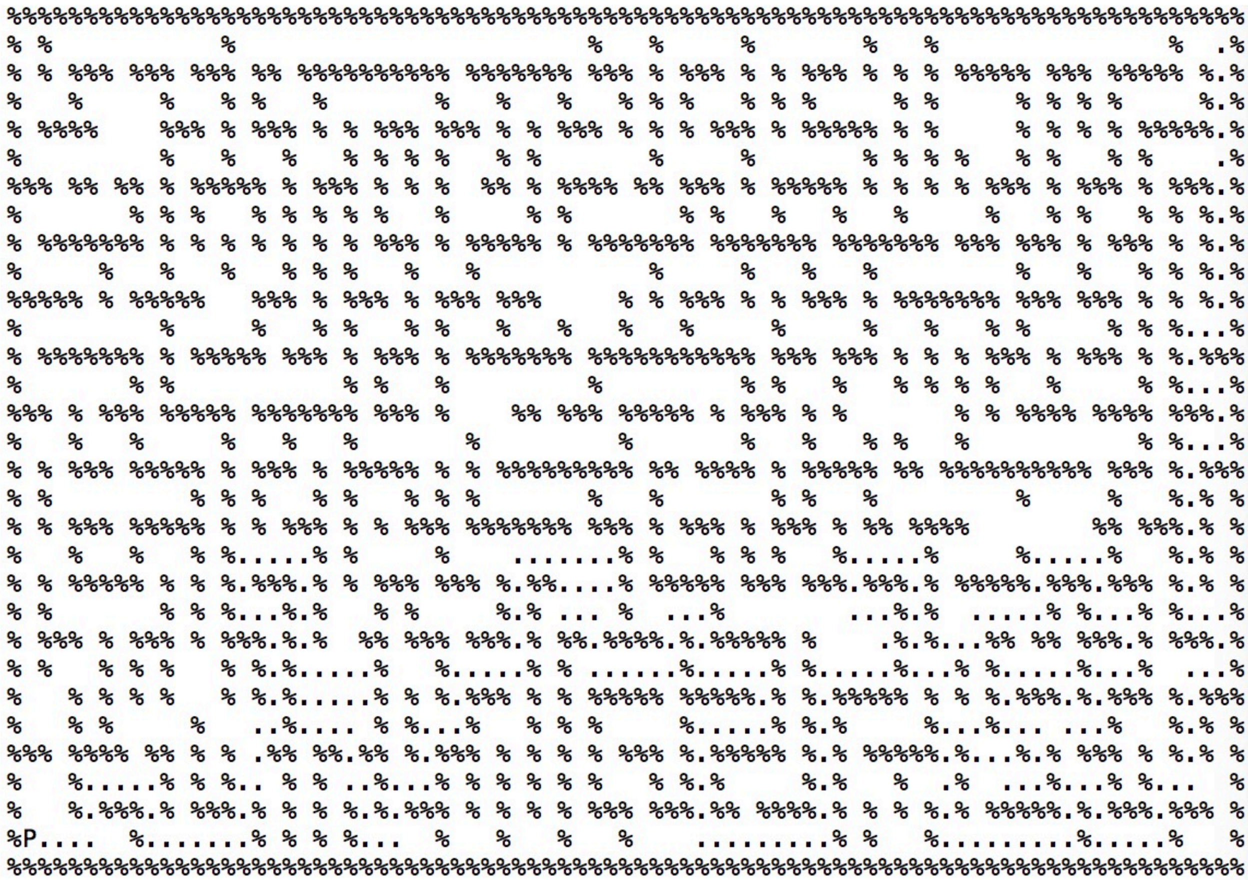
The expand points of GBFS for openMaze is 501 and the steps (cost) to find the target is 53.

MediumMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%P..  %       %             %         %     %           %   %
%%%.%%% % %%%%% %%%%% %%%%% %%% %%%%%%% % %%% % %%%%%%% % %%%
%...%.........%   % %   % %   %         %   % %     % % %   %
%.%%%.%%% %%%.%%% % %%% % %%% % %%%%%% %%%% % %%%%% % % %%% %
%.%...% %   %.%...%...% %                 % %   % % %       %
%...%%% % % %.%.%.%.%.% %%% % %%%%%%% %%% % %%% % % %%%%%%% %
% %   %   % %...%...%.%   % %     %   %   %     % %   %   % %
% %%%%%%% % % %%% %%%.%%% % %%% %%% % % %%%%%%%%% %%% % % % %
%   %   % %       % %.%   %   % %   % % %     %     %   % % %
% % %%% % %%% %%%%% %.% %%%%% % % %%% % % %%% %%%%% %%%%% %%%
% %   % %   %      ...% %   % %     %   % % %           %   %
% %%%%% %%%%% %%%%%.%%% % % % %%%%%%%%% % % %%% %%% %%% %%% %
%     %       %    .....% % %  .......%   %     %.....%   % %
% %%% %%% %%%%% %%%%% %.%%% %%%.%%%%%.%%%%%% %%%%.%%%.%%% % %
%   %     %     %   % %.........% % %...%.....%...%  ...% % %
% % %%% %%% %%% %%% % %%% %%%% %% % %%%.%.%%%.%.%%% %%%.%%% %
% %   %   %       %       %       %   %...% %.%.%     %...% %
% % %%% % %%%% %% %%%%%%%%% %%%%% %%% % %%% %.%.% % %%%%%.% %
% %     %   %     %       %   %       %     %...% % %   %.% %
% %%%% %% % % %%%%% %%%%% %%% % %%%% %% %%% %% %% %%% % %.% %
%         % %           %     %           %           % %...%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of GBFS for mediumMaze is 125 and the steps (cost) to find the target is 120.

BigMaze



The expand points of GBFS for bigMaze is 307 and the steps to find the target is 260.

A* Search for Single-Food Maze

A* is one of the heuristic based function to find the shortest path to the target. The function F = G + H should be implement here. G is the step from start point to current position and H is implement by Manhattan distance. Priority queue should be used here to find the lowest F in the openlist.

OpenMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                     %P            %
%                     %.            %
%                     %.            %
%                     %.            %
%                     %........     %
%                     %%%%%%%%.     %
%                            %.     %
%                            %.     %
%                            %.     %
%                            %.     %
%     ...................    %.     %
%     .%%%%%%%%%%%%%%%%%.......     %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%                            %
%     .%%%%                         %
%     ....%                         %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

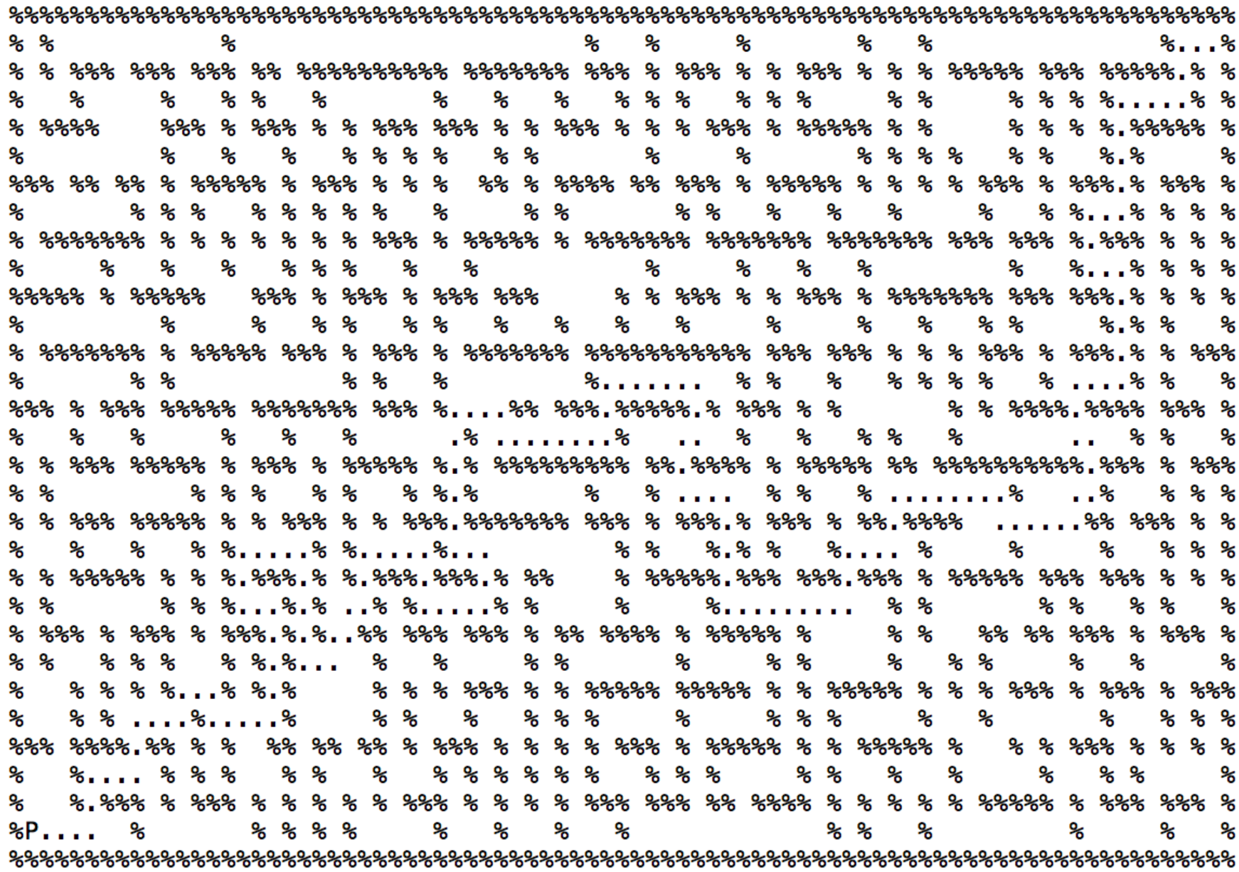
The expand points of A* is 349 and the steps to find the target is 53.

MediumMaze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%P..  %       %             %         %     %           %   %
%%%.%%% % %%%%% %%%%% %%%%% %%% %%%%%%% % %%% % %%%%%%% % %%%
%...%.....    %   % %   % %   %         %   % %     % % %   %
%.%%%.%%%.%%% %%% % %%% % %%% % %%%%%% %%%% % %%%%% % % %%% %
%.%...% %...% %   %   % %                 % %   % % %       %
%...%%% % %.% % % % % % %%% % %%%%%%% %%% % %%% % % %%%%%%% %
% %   %   %.%   %   % %   % %     %   %   %     % %   %   % %
% %%%%%%% %.% %%% %%% %%% % %%% %%% % % %%%%%%%%% %%% % % % %
%   %   % %...    % % %   %   % %   % % %     %     %   % % %
% % %%% % %%%.%%%%% % % %%%%% % % %%% % % %%% %%%%% %%%%% %%%
% %   % %   %.......  % %   % %     %   % % %           %   %
% %%%%% %%%%% %%%%%.%%% % % % %%%%%%%%% % % %%% %%% %%% %%% %
%     %       %    .....% % %         %   %     %     %   % %
% %%% %%% %%%%% %%%%% %.%%% %%% %%%%% %%%%%% %%%% %%% %%% % %
%   %     %     %   % %........ % % %   %     %   %.....% % %
% % %%% %%% %%% %%% % %%% %%%%.%% % %%% % %%% % %%%.%%%.%%% %
% %   %   %       %       %   ....%   %   % % % %...  %...% %
% % %%% % %%%% %% %%%%%%%%% %%%%%.%%% % %%% % % %.% %%%%%.% %
% %     %   %     %       %   %  .... %.....%   %.% %   %.% %
% %%%% %% % % %%%%% %%%%% %%% % %%%%.%%.%%%.%% %%.%%% % %.% %
%         % %           %     %     ....  %.......    % %...%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The expand points of A* is 464 and the steps to find the target is 104.

BigMaze



The expand points of A* is 1129 and the steps to find the target is 156.

2. Search with Multiple Dots

For this part, we utilize the A* algorithms to implement the task. While instead of using Manhattan Distance as the heuristic function, we select the Minimum Spanning Tree (MST). The core idea is: for the present node, we may have several directions to go, i.e., several successor points for the next step, we then calculate the total weights of the MST formed by each of the successor point, individually, with the dots which are not eaten yet, and next pick up the one with the smallest weights value as the next node. To calculate the weight of the MST, we firstly use BFS to calculate the true distance of each pair of points in the MST, for a much more precise result. Though we tried our best to execute this, we still face some problems like the final result is not so perfect and the output path for medium maze encountered some problem. Even though we cannot fix these problems now, we will continue working on it after the deadline of this mp.

Tiny Maze

```
%%%%%%%%%%
%...%   .%
%.%.% %%.%
%.%....%.%
%..%P%...%
%.... ...%
% %%%%.%.%
%......% %
%%%%%%%%%%
```

The nodes expanded are 168 and the cost is 40

Small Maze

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%.     P..     %...........  %
%...%%%%%.%%%%%%.%. % %.%%...%
%. .%  % .   %  .%. % %. %...%
%......% ........%.   %. %%%%%
%%%%%.%%%% %%% .%%%%%%%.     %
%.................    %.%%%  %
%%.%%%%%%%%.%%%%%%%%%%%.%.   %
% .     %  .............%.%%%%
%..     %%%%%.    %.......   %
%.% %%%    % .%   %% %%.%%%%%%
%          % .%        .     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

The nodes expanded are 1968 and the cost is 185

As for the Medium Maze, we didn't output the path image, though we get:
Nodes expanded: 3443
Cost: 290
Through our algorithms.