German University in Cairo
Department of Computer Science
Assoc. Prof. Haythem O. Ismail
Ammar Yasser
Ahmed Hashem

Introduction to Artificial Intelligence, Winter Term 2021
Project 1
The Matrix: Escaped[1]

Due: November 29th

1. Project Description

The year is 2200 and the machines took over the world after a long and grueling battle the likes of which were never seen before. Most of humanity was defeated and they got their memories erased and then put into deep sleep. In this state, their brains are used as a huge neural network by the machines. To harness the power of the humans' brains, the machines created a simulation called *the matrix* where humans who are asleep think that in fact they are alive in. After the war, a very few number of humans were able to escape the wrath of the machines and they started planning how to avenge their loss and save the human race. A prophecy was told that there will come someone from within the matrix who will be the chosen savior of humanity. This person is called *Neo*. The living were able to get to the matrix and they were able to locate Neo and get him finally awake. Now, Neo get in and out of the matrix when he can to save other humans.

The machines started noticing a weird pattern of behavior in the matrix and hence they created a virus called agent *Smith* that should track Neo and kill him whenever he sees him in the matrix. In order to do so, agent Smith made a lot of copies of himself and decided to set a trap for Neo. They (the copies of agent Smith) took some of the humans Neo would save as hostages and injected them with a slow spreading chemical that would eventually kill them and turn them into agents. If a human dies in the matrix their brain stops and they die in real life. Hence, Neo, on sensing that some humans are dying, rushed to the matrix in order to save the humans. The agents do not know that Neo has special skills and that he foresaw the agents' plan. As such, Neo planted a number of pills that would restore his health and the health of the hostages once activated and a number of launching pads that will let him fly from one to the other. Also, *Neo (on carrying a hostage) can stop the spread of the virus from turning the hostages into agents upon dying. However, he can not stop them from dying.*

Hence, in order to limit the influence of the machines, *Neo's goal is to take as many humans as possible alive to a special location called the* **telephone booth** *where they can get out of the matrix. However, if hostages die and turn into agents, Neo would have to kill these agents. Further, if a hostage dies while being carried by Neo, Neo would also return it to the telephone booth so that the body would not become an agent in the future.*

The area the hostages are held in can be thought of as an $m \times n$ grid of cells where $5 \leq m, n \leq 15$. Initially, a grid cell is either free or contains one of the following: Neo, a hostage, a pill, a pad, an agent, or the telephone booth. It is also worth noting that initially *there will not be any overlapping in a single cell*. Meaning, a single cell will

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[1]This project's theme is based on the Matrix move franchise.

contain only one type of object. Put simply, there will not be a case where Neo starts from the same place as the telephone booth, or a hostage is at the same cell as a pill and so on. *Neo can not be at the same cell as an agent but can enter all other cells.*

In this project, you will use *search* to help Neo complete his mission. **Neo's mission is to end up at the telephone booth with all hostages that did not turn agents returned (whether dead or alive) and, in the case hostages die and turn into agents, each hostage that turned into an agent killed.**

Neo can:

- Move in all four directions as long as there **are no agents in the cell Neo is heading towards**.
- Carry a hostage only if both of them are in the same cell. Once a hostage is carried, it can only be dropped in the telephone booth.
- Drop all hostages currently being carried at the telephone booth only if Neo is in the same cell where the telephone booth lies.
- kill **all agents at neighboring cells** to Neo. Neighboring cells are the top, the bottom, the left, and the right cells. Diagonal cells are not neighboring cells.
- Take a pill to increase his health and the health of all **currently living hostages**. A pill could be taken **only once**.
- Fly from one launching pad to the next.

Neo can only carry up to c hostages at a time. Accordingly, Neo might have to make multiple trips to the telephone booth to transport all the hostages. The hostages, will continue to incur damage with every passing time step. A time step is the duration taken by Neo to complete one action. With every time step, the damage of any hostage increases by 2. If the damage of a hostage reaches 100, **the hostage dies**. There are two cases to a hostage dying:

- If a hostage was never carried by Neo dies, this hostage **turns into an agent and then Neo must kill this agent**.
- If a hostage is being carried by Neo dies, this hostage will **not turn into an agent and Neo will keep carrying its dead body**.

Every time Neo *performs a kill action* (regardless of the number of agents killed by this action), Neo's damage increases by 20. Every time Neo takes a pill the damage of Neo and all living hostages decreases by 20. Note that in this case where the action is taking a pill, the damage of living hostages will not increase by 2 then decrease by 20 leading in a decrease of 18, it will be simply a decrease of 20. Note that damage should not get below zero. If Neo's damage reaches 100 he dies and the game is over.

Using search you should formulate a plan that Neo can follow to complete the mission. An optimal plan is one where the deaths (of hostages) are at a minimum as a first condition. Given two plans with the same number of deaths, the more optimal plan is the one where the total number of agents killed is minimal. The following search strategies will be implemented and each will be used to help Neo:

a) Breadth-first search.
b) Depth-first search.
c) Iterative deepening search.
d) Uniform-cost search.

e) Greedy search with at least two heuristics.

f) A* search with at least two *admissible* heuristics.

Each of the aforementioned strategies should be tested and compared in terms of RAM usage, CPU utilization, and the number of search tree nodes expanded. **You must only use Java 8 to implement this project.**

Your implementation should have two main functions `genGrid` and `solve`:

- `genGrid()` generates a random grid. The dimensions of the grid, the starting position of Neo and the telephone booth, as well as the number and locations of the hostages, agents, pills, and pads are to be randomly generated. You need to make sure that the dimensions of the generated grid is between 5×5 and 15×15 and the number of generated hostages is between 3 and 10. For every hostage, a random starting damage between 1 and 99 should also be generated. Also, pads come in pairs. Meaning, pad P_1 must be generated with another pad P_2 where Neo can fly from P_1 to P_2 and vice versa. The number of hostages Neo can carry c should be randomly generated as well where $c \leq 4$. The number of pills **should be less than or equal to the number of hostages**. There are **no restrictions on the maximum number of agents or pads** (as long as no overlapping occurs and there are enough cells in the grid).

- `solve(String grid, String strategy, boolean visualize)` uses search to try to formulate a winning plan:
  - *grid* is a string representing the grid to perform the search on. This string should be in the following format:
    M,N; C; NeoX,NeoY; TelephoneX,TelehoneY;
    AgentX$_1$,AgentY$_1$, ...,AgentX$_k$,AgentY$_k$;
    PillX$_1$,PillY$_1$, ...,PillX$_g$,PillY$_g$;
    StartPadX$_1$,StartPadY$_1$,FinishPadX$_1$,FinishPadY$_1$,...,
    StartPadX$_l$,StartPadY$_l$,FinishPadX$_l$,FinishPadY$_l$;
    HostageX$_1$,HostageY$_1$,HostageDamage$_1$, ...,HostageX$_w$,HostageY$_w$,HostageDamage$_w$

    where:
    * `M` and `N` represent the width and height of the grid respectively.
    * `C` is the maximum number of members Neo can carry at a time.
    * `NeoX` and `NeoY` represent the x and y starting positions of Neo.
    * `TelephoneX` and `TelephoneY` represent the x and y positions of the telephone booth.
    * `AgentX`$_i$,`AgentY`$_i$ represent the x and y position of agent i where $1 \leq i \leq k$ and k is the total number of agents.
    * `PillX`$_i$,`PillY`$_i$ represent the x and y position of pill i where $1 \leq i \leq g$ and g is the total number of pills.
    * `StartPadX`$_i$,`StartPadY`$_i$ represent the x and y position of pad i where $1 \leq i \leq l$ and l is the total number of pads. Moreover `FinishPadX`$_i$,`FinishPadY`$_i$ represent the x and y position of the target pad stated by `StartPadX`$_i$ and `StartPadY`$_i$. For example, if `StartPadX` $= 1$, `StartPadY` $= 2$, `FinishPadX` $= 3$, and `FinishPadY` $= 4$, this means that Neo can fly directly from cell $(1, 2)$ to cell $(3, 4)$. Further, if $1, 2, 3, 4$ is in the string, then the string must also contain $3, 4, 1, 2$. That is, Neo could fly from cell $(3, 4)$ to cell $(1, 2)$ instantly. A **pad lets Neo fly to only one other pad**.

* HostageX_i,HostageY_i,HostageDamage_i represent the x and y position and current damage of hostage i where $1 \leq i \leq w$ and w is the total number of hostages.

  Note that the string representing the grid does not contain any spaces or new lines. It is just formatted this way to make it more readable. All x and y positions are assuming 0-indexing.

  – *strategy* is a symbol indicating the search strategy to be applied:
    * BF for breadth-first search,
    * DF for depth-first search,
    * ID for iterative deepening search,
    * UC for uniform cost search,
    * GRi for greedy search, with $i \in \{1, 2\}$ distinguishing the two heuristics, and
    * ASi for A* search, with $i \in \{1, 2\}$ distinguishing the two heuristics.

  – *visualize* is a boolean parameter which, when set to true, results in your program's side-effecting a visual presentation of the grid as it undergoes the different steps of the discovered solution (if one was discovered). *A GUI is not mandatory (though welcomed), printing in the console would suffice.*

  The function returns a String of the following format: plan;deaths;kills;nodes where

  – plan is a string representing the operators Neo needs to follow separated by commas. The possible operator names are: up, down, left, right, carry, drop, takePill, kill, and fly.
  – deaths is a number representing the number of dead hostages in the found goal state (whether they turned into agents or not).
  – kills is a number representing the number of killed agents in the found goal state (including the number of agents that were hostages before).
  – nodes is the number of nodes chosen for expansion during the search.

2. **Sample Input/Output:**

   Example Input Grid: 5,5;2;0,4;1,4;0,1,1,1,2,1,3,1,3,3,3,4;1,0,2,4;0,3,4,3,4,3,0,3; 0,0,30,3,0,80,4,4,80

H (30)	A		Pad (4,3)	Neo
P	A			TB
	A			P
H (80)	A		A	A
			Pad (0,3)	H (80)

   TB represents the telephone booth, H (D) represents a hostage with initial damage D, Pad (X,Y) represents a pad that lets Neo fly towards cell (X,Y), A represents an agent and P represents a pill.

   Example Output:
   left,fly,right,carry,left,fly,down,right,drop,left,left,kill,left,left
   up,carry,down,down,kill,up,right,right,right,right,drop;1;3;1246837

   Explanation:
   Notice that in this solution, Neo first saves the hostage highlighted in green, then he

attempts to carry the hostage highlighted in brown. However, while attempting this, the hostage highlighted in red dies and turns into an agent (as Neo never carried it). As such, Neo must kill the red hostage. Moreover, while Neo was killing the red hostage, the red agent is also in a neighboring cell and hence it is killed. Further, in this particular solution, Neo killed the agent highlighted in blue which means that this is a sub-optimal solution.

3. **Groups:** You may work in groups of *at most* four.

4. **Deliverables**

   a) Source code.
      - You should implement a data type for a search-tree node as presented in class.
      - You should implement an abstract data type for a generic search problem, as presented in class.
      - You should implement the generic search procedure presented in class, taking a problem and a search strategy as inputs. *You should make sure that your implementation of search does not allow repeated states and that all your search strategies terminate as per the time constraints of the automated public test cases that will be posted.*
      - You should implement a `Matrix` subclass of the generic search problem. This class must contain `genGrid()` and `solve` as *static* methods.
      - You should implement all of the search strategies indicated above together with the required heuristics. A trivial heuristic (e.g. $h(n) = 1$) is *not* acceptable. You should make sure that your heuristic function runs in maximum *polynomial* time in the size of the state representation.
      - Your program will be subject to both public and private test cases.
      - Your source doe should have two packages. A package called *tests* and a package called *code*. All your code should be located in the *code* package and the test cases (when posted) should be imported in the *tests* package.
      - Part of the grade will be on how readable your code is. Use explanatory comments whenever possible.

   b) Project Report, including the following.
      - A discussion of your implementation of the search-tree node ADT.
      - A discussion of your implementation of the Matrix problem.
      - A description of the main functions you implemented.
      - A discussion of how you implemented the various search algorithms.
      - A discussion of the heuristic functions you employed and, in the case of A*, an argument for their admissibility.
      - At least two running examples from your implementation.
      - A comparison of the performance of the implemented search strategies on your running examples in terms of completeness, optimality, RAM usage, CPU utilization, and the number of expanded nodes. You should comment on the differences in the RAM usage, CPU utilization, and the number of expanded nodes between the implemented search strategies.
      - Proper citation of any sources you might have consulted in the course of completing the project. *Under no condition*, you may use on-line code as part of your implementation.
      - If your program does not run, your report should include a discussion of what you think the problem is and any suggestions you might have for solving it.

5. Important Dates

Teams. Make sure you submit your team members' details by <u>October 30th at 23:59</u> using the following link `https://forms.gle/tm72z5BeSLQN41dm8`. Only one team member should submit this for the whole team. After this deadline, we will be posting on the MET/CMS a team ID for each submitted team. You will be using this team ID for submission.

Source code and report. <u>Online submission</u> by <u>November 29th at 23:59</u>. The submission details will be announced after the team submission deadline.

Brainstorming session. In tutorials.